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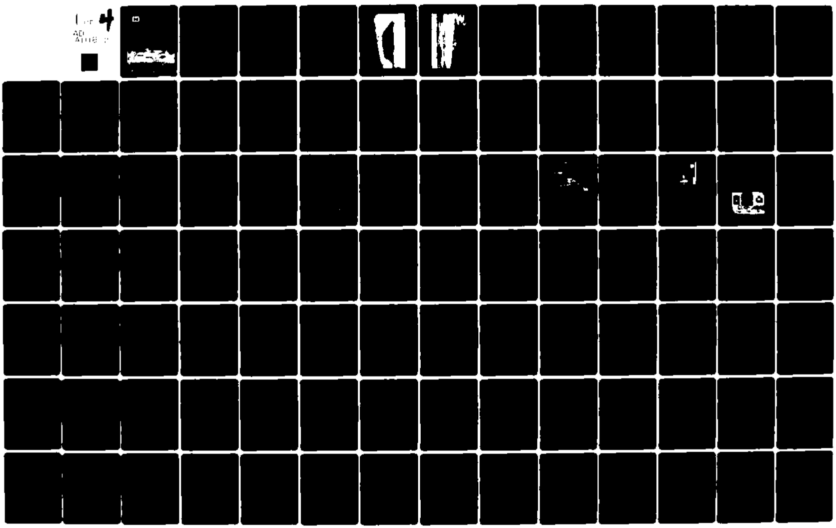

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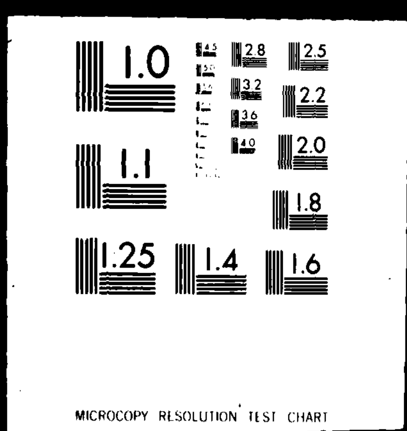

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TECHNICAL REPORT HL-81-14

# VERIFICATION OF THE CHESAPEAKE BAY MODEL

## Chesapeake Bay Hydraulic Model Investigation


by

Norman W. Scheffner, Leroy G. Crosby, David F. Bastian
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December 1981

Final Report







Prepared for U. S. Army Engineer District, Baltimore
Baltimore, Maryland 21203

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER<br>Technical Report HL-81-14 | 2. GOVT ACCESSION NO.<br>AD-A111812 | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>VERIFICATION OF THE CHESAPEAKE BAY MODEL; Chesapeake Bay Hydraulic Model Investigation | | 5. TYPE OF REPORT & PERIOD COVERED<br>Final report |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>Norman W. Scheffner, A. Michael Chambers, Leroy G. Crosby, Mitchell A. Granat, David F. Bastian | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>U. S. Army Engineer Waterways Experiment Station<br>Hydraulics Laboratory<br>P. O. Box 631, Vicksburg, Miss. 39180 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>U. S. Army Engineer District, Baltimore<br>P. O. Box 1715<br>Baltimore, Md. 21203 | | 12. REPORT DATE<br>December 1981 |
| | | 13. NUMBER OF PAGES<br>275 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Chesapeake Bay (Md. and Va.)
Computer control
Data analysis
Fixed-bed models
Hydraulic models
Instrumentation
Velocity measurement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Chesapeake Bay model, a fixed-bed model constructed to a horizontal scale ratio of 1:1000 and a vertical scale ratio of 1:100, reproduced the Chesapeake Bay from the ocean to the head of tides for each tributary. Reproduction extended to the +20 ft contour. The model was equipped with the necessary appurtenances to accurately reproduce and measure tidal heights, tidal currents, salinity distributions, and freshwater inflows. Due to the immense size of the

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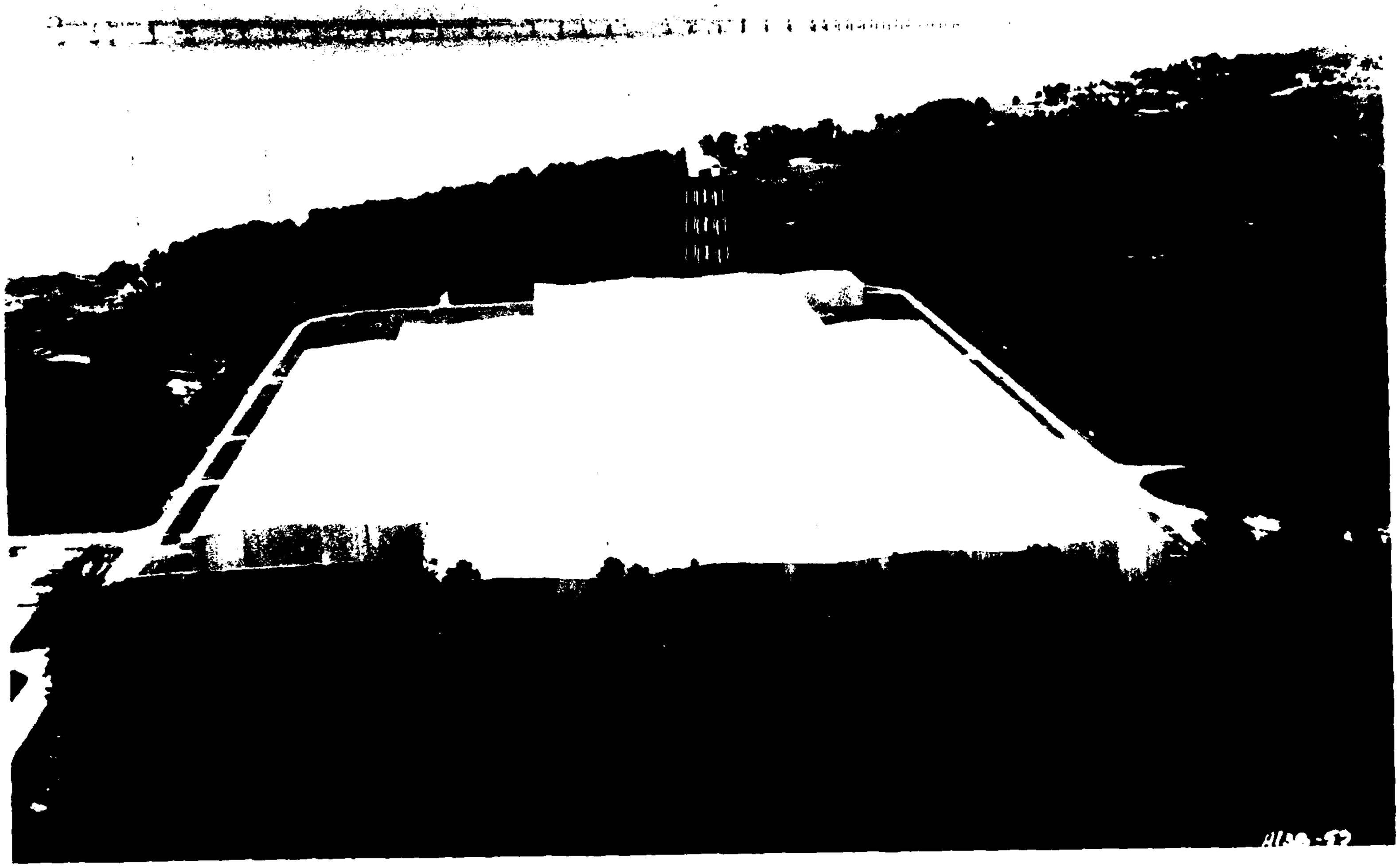
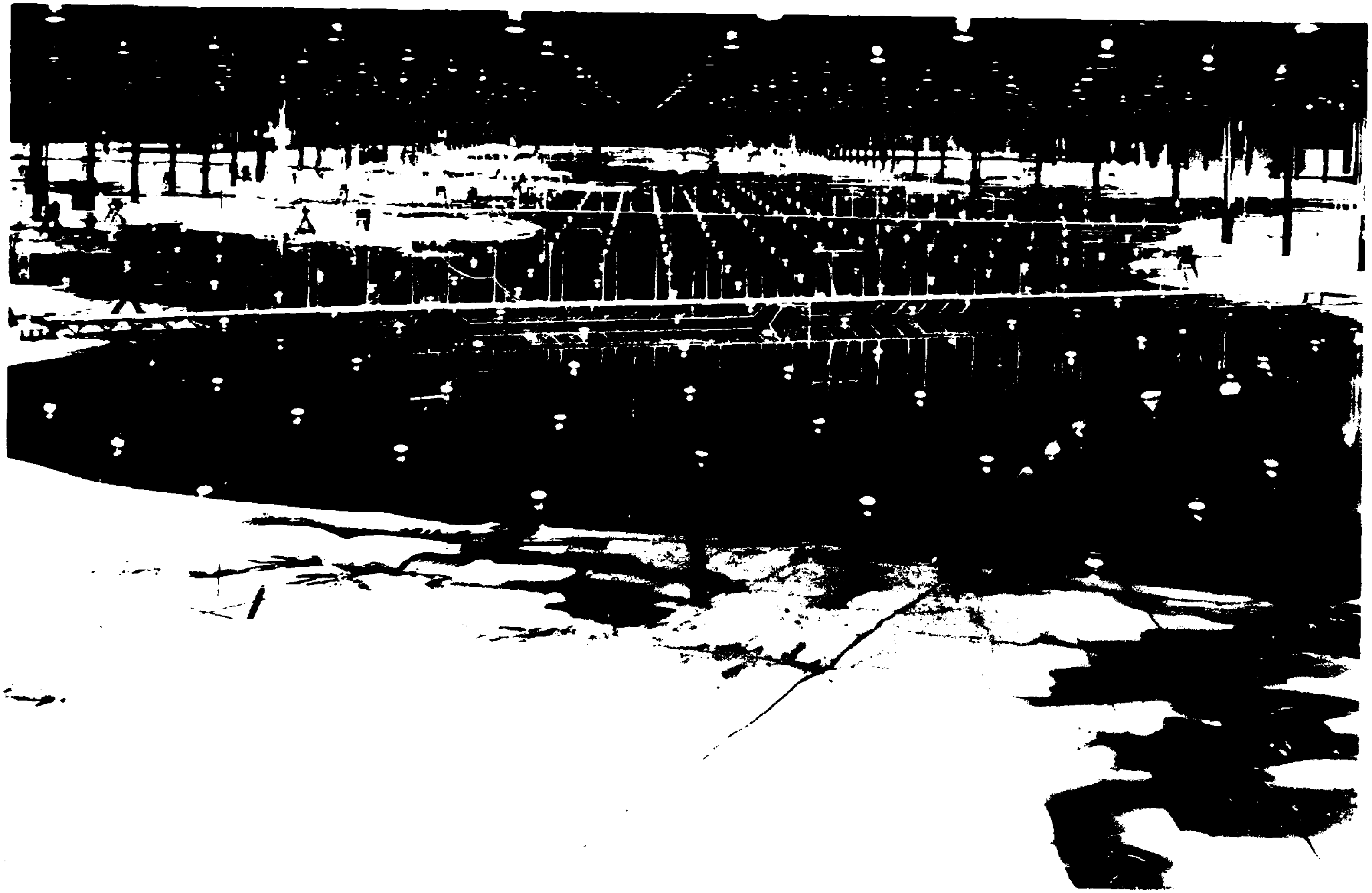
20. ABSTRACT (Continued).

model (8.6-acre model housed in a 14-acre building), complete computer control and data aquisition capabilities were provided. Severe limitations in prototype data in addition to substantial wind contamination of those data necessitated a detailed data analysis program which resulted in a modified approach to physical model verification. This was accomplished in the following two separate modes of operation: (a) verification for tidal heights and tidal velocities using an $M_2$ constituent tide and a constant long-term freshwater inflow and (b) verification for salinities using a typical 28-day tidal cycle (with long-period wind energy filtered out) and inflow hydrographs reproduced in 2-week time-steps. A bubbler system was incorporated in the model to statistically reproduce the vertical mixing caused by wind fields acting on the prototype. Excellent verification of the model was achieved.



Aerial photograph of Chesapeake Bay model



Interior of Chesapeake Bay model

## PREFACE

A request for the U. S. Army Engineer Waterways Experiment Station (WES) to conduct a hydraulic model investigation was made by the U. S. Army Engineer District, Baltimore (NAB), under the direction of the Rivers and Harbors Act of 1965. Prototype data collection was contracted by NAB to various institutions in the Chesapeake Bay area.

The study was undertaken by the Chesapeake Bay Model Branch, Estuaries Division, Hydraulics Laboratory, WES, under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory; F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; R. A. Sager, Chief of the Estuaries Division; and T. Hill, D. F. Bastian, and R. O. Bruno, Chiefs of the Chesapeake Bay Model Branch. The architectural and engineering design of the model shelter was provided by the firm of Whitman, Requardt, and Associates of Baltimore, Maryland. The model was operated by a contractor, Acres American, Inc., under the direction of Dr. J. W. Hayden during the latter part of the verification. Additional WES personnel making a significant contribution to the design, construction, and verification were Messrs. A. M. Chambers, L. G. Crosby, R. Garner, M. Granat, S. B. Heltzel, H. J. Rhodes, Jr., and N. W. Scheffner, MAJ M. Moran, Ms. V. R. Pankow, and Dr. R. E. Nece. WES personnel involved with instrumentation and computer activities were Messrs. J. V. Tarver, J. H. G. Shingler, B. W. McCleave, N. W. Scheffner, and L. G. Crosby. Additional Acres American, Inc., personnel significantly involved in verification of the model were Messrs. T. R. Raster, S. G. Bridgeman, W. M. Dyok, and H. W. Whetzel. Dr. R. H. Multer provided valuable technical guidance during the design and verification of the model. This report was prepared by Mr. Scheffner with the assistance of Messrs. Chambers, Granat, Crosby, and Bastian. Mr. Herrmann provided detailed guidance during the preparation of the report.

Commanders and Directors of WES during this investigation and the preparation and publication of this report were COL L. A. Brown, CE, BG E. D. Peixotto, CE, COL G. H. Hilt, CE, COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converced to metric (SI) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| acres | 4046.856 | square metres |
| cubic feet per second | 0.02831685 | cubic metres per second |
| Fahrenheit degrees | 5/9 | Celsius degrees or Kelvins* |
| feet | 0.3048 | metres |
| feet per second | 0.3048 | metres per second |
| gallons | 3.785412 | cubic decimetres |
| gallons per minute | 3.785412 | cubic decimetres per minute |
| inches | 25.4 | millimetres |
| knots (international) | 0.5144444 | metres per second |
| miles (U. S. nautical) | 1.852 | kilometres |
| miles (U. S. statute) | 1.609344 | kilometres |
| pounds (force) per square inch | 6894.757 | pascals |
| square miles (U. S. statute) | 2.589998 | square kilometres |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

# VERIFICATION OF THE CHESAPEAKE BAY MODEL

## Hydraulic Model Investigation

## PART I: INTRODUCTION

### Chesapeake Bay

1. Chesapeake Bay is an unusually long and shallow estuary oriented on a north-south axis on the eastern coastline of the United States. The bay extends appoximately 190 miles* north from its mouth, located in the Commonwealth of Virginia between Cape Henry and Cape Charles, to the Susquehanna River in the State of Maryland (Figure 1). The bay has an average depth of approximately 28 ft and a maximum width of approximately 30 miles. Over 64,000 square miles of drainage basin empty into the partially mixed estuary. In geologic terms, Chesapeake Bay is a submerged river valley and may be considered a dynamic remnant of the ancestral Susquehanna River. Of the rivers emptying into the bay, freshwater inflow is derived primarily from five western shore river systems. Of these river systems, the James, York, Rappahannock, Potomac, and Susquehanna, the Susquehanna River contributes approximately one-half of the total bay freshwater inflow.

2. The bay is unique in that it is one of the few embayments able to contain one semidiurnal tidal wave at all times (Hicks 1964). Tides in the bay are predominantly semidiurnal and are characterized by low amplitudes (under 2 ft at most locations). The external hydrodynamic forces acting on the bay are primarily due to the astronomical tides, wind stresses, and Coriolis force. Internal forces include density currents due to salinity and temperature gradients and energy dissipation due to viscosity and boundary friction effects.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

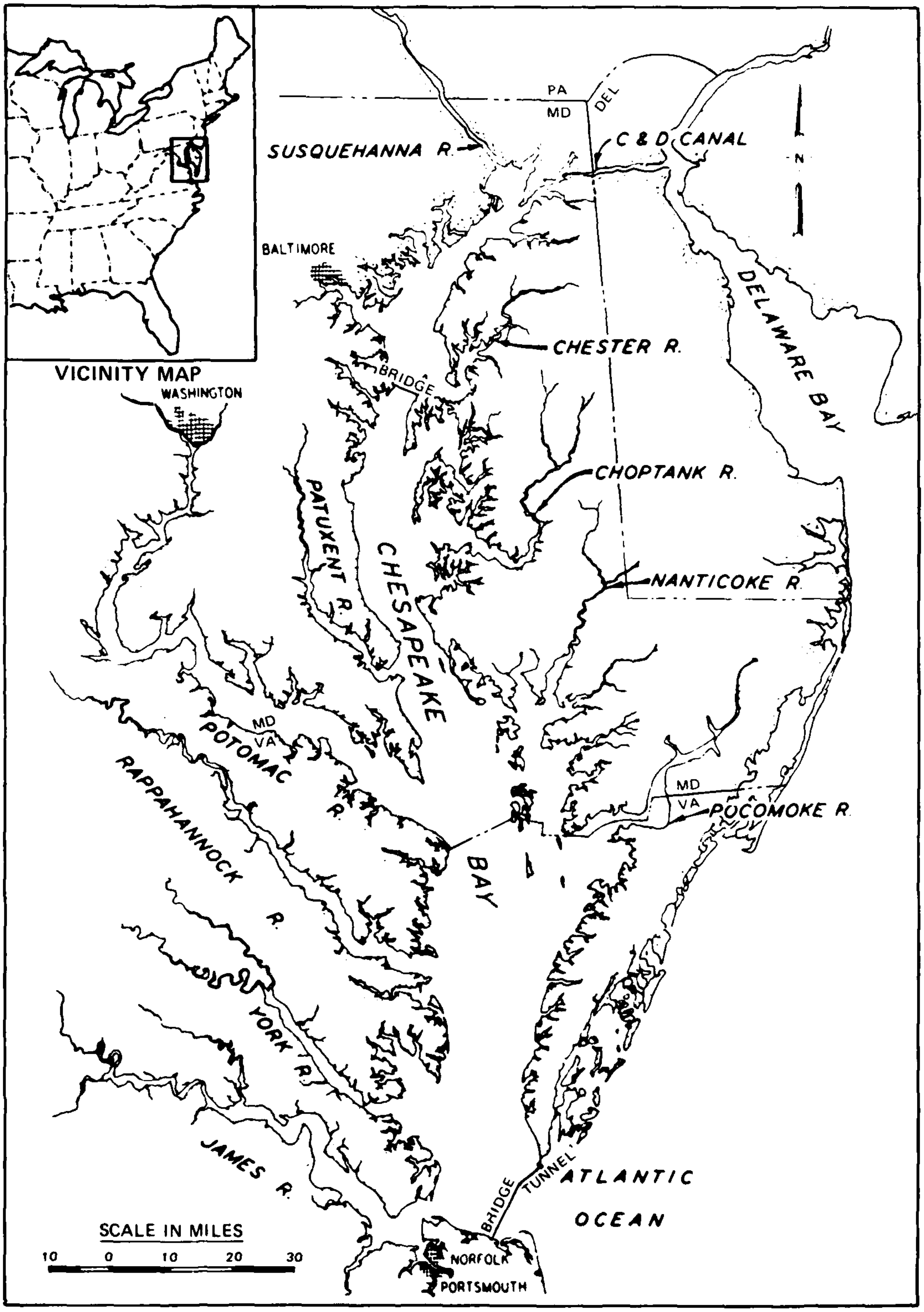



Figure 1. Location map

## Authorization for Model

3. Recently, the Chesapeake Bay has been a source of concern to the people who use the bay and live around it. This concern stems primarily from the problems of incompatibility of the various uses of the bay and has been brought to full focus by increased environmental awareness of growing pollution and water supply problems stemming from the growth in population around the bay.

4. Any viable study addressing water utilization and control would have to base its decisions on a hydrodynamic model of some type which had been verified by reproduction of past events occurring on the bay. Since physical models of estuarine systems have proven themselves as effective tools in the reproduction of estuarine behavior, Congress authorized the construction of a physical model of the Chesapeake Bay system. This action was authorized by Section 312 of the Rivers and Harbors Act of 1965 (PL 89-298). The U. S. Army Engineer Waterways Experiment Station (WES) was selected by the U. S. Army Engineer District, Baltimore (NAB), to perform the job of designing, building, verifying, and testing the physical model of Chesapeake Bay.

## Objective of the Model

5. The objective of the model, as stated in Section 312 of the Rivers and Harbors Act, reads as follows:

> The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin, including the waters of the Baltimore Harbor and including, but not limited to, the following: navigation, fisheries, flood control, control of noxious weeds, water pollution, water quality control, beach erosion, and recreation.

An expanded explanation of the objectives of the model can be found in "Chesapeake Bay Future Conditions Report" (U. S. Army Engineer District, Baltimore, 1978).

6. In order to accomplish any specific objective, the physical model would have to be capable of the reproduction of prototype tides, velocities, salinities, and freshwater inflows into the bay system. When these goals have been realized, predictions of the response of the bay to future conditions can be accurately made.

## PART II: PROTOTYPE DATA COLLECTION PROGRAM

7. Prototype data for use in verification of the Chesapeake Bay model were obtained through contracts with various agencies. This prototype data collection program was designed by WES and the data collection contracts were funded and managed by NAB. The organizations involved were the National Oceanic and Atmospheric Administration (NOAA), the Chesapeake Bay Institute of Johns Hopkins University, the Chesapeake Biological Laboratory of the University of Maryland, and the Virginia Institute of Marine Sciences. Existing data were also obtained from the U. S. Geological Survey (USGS), Maryland State Department of Natural Resources, and the National Weather Service.

8. Due to physical limitations imposed by the size of the bay, synoptic data of the entire estuarine system were not possible. Regional and site-specific data were taken for varying durations during the period 1970-1974. These data consisted of tidal heights, tidal velocities, salinities, stream gage measurements, and wind velocities. Tidal height data were provided for 72 of the 75 NOAA tide stations located throughout the bay (Figure 2). Data were not provided for sta 1, 39, and 57. Velocity data were collected at 205 stations and salinity data were collected at 199 stations. Figure 3 is a composite map showing the ranges of velocity and salinity stations sampled during the 28 discrete sampling periods. Each range contains from 1 to 11 separate stations spaced nearly uniformly across the range (see Tables 7 and 8). Each station contained multiple sets of data corresponding to a surface measurement (2 to 4 ft below surface) and generally a data series for each 10-ft increment of depth extending to the channel bottom (2 to 4 ft above bottom). A total of 770 velocity data series and 781 salinity data series were obtained. The continuous velocity data were on the average of 5 days duration, while salinity data were generally collected half-hourly during 13 continuous daylight hours for three consecutive days concurrent with the velocity sampling periods. In addition to these data, approximately monthly slack-water salinity cruise data for the 4-year collection period were available for selected main bay stations

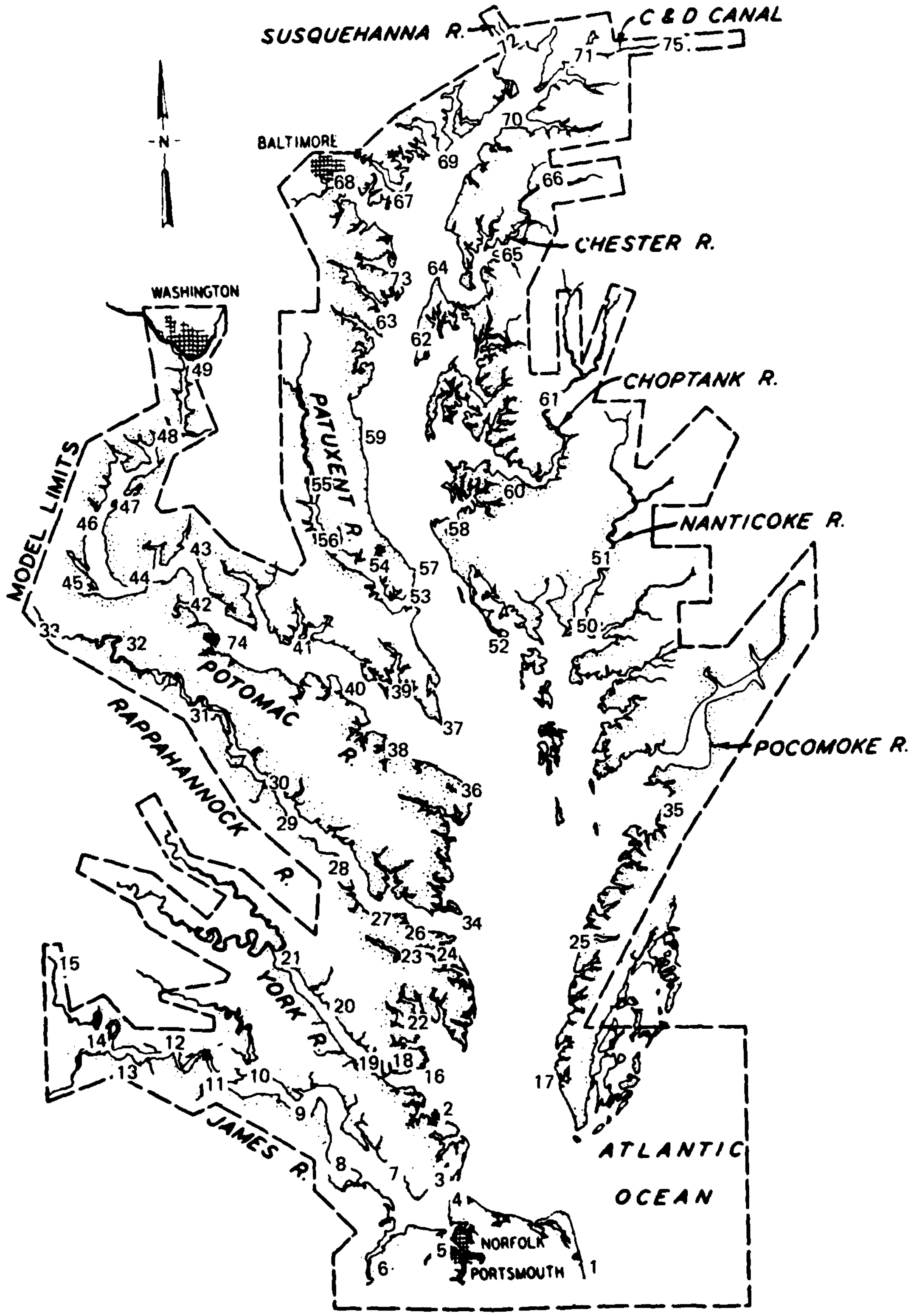
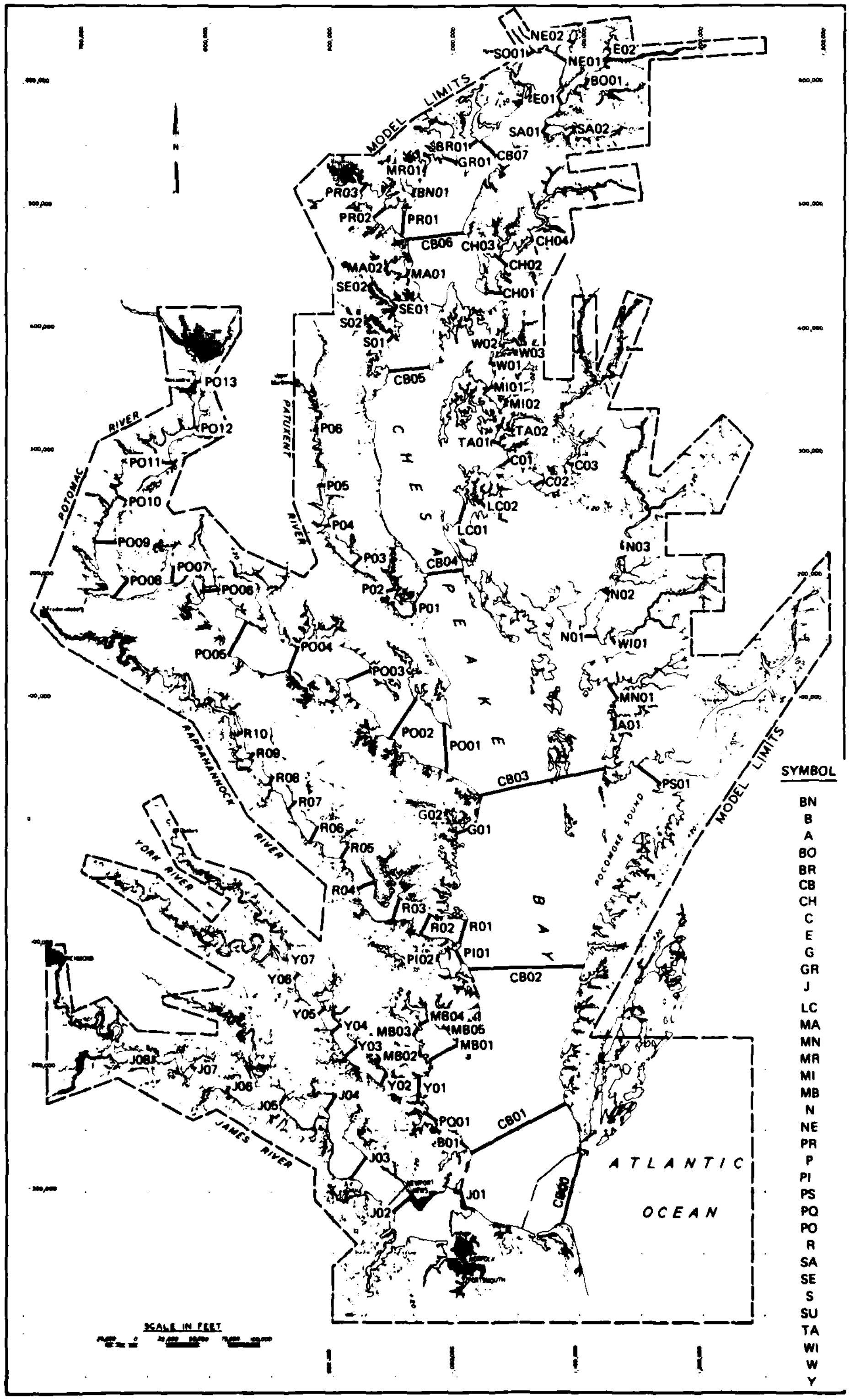



Figure 2. Tide height stations




| SYMBOL | RIVER |
|---|---|
| BN | BACK RIVER NORTH |
| B | BACK RIVER SOUTH |
| A | BIG ANNEMESSEX |
| BO | BOHEMIA |
| BR | BUSH |
| CB | CHESAPEAKE BAY |
| CH | CHESTER |
| C | CHOPTANK |
| E | ELK |
| G | GREAT WICOMICO |
| GR | GUN POWDER |
| J | JAMES RIVER |
| LC | LITTLE CHOPTANK |
| MA | MAGOTHY |
| MN | MANOKIN |
| MR | MIDDLE |
| MI | MILES |
| MB | MOBJACK BAY |
| N | NANTICOKE |
| NE | NORTH EAST |
| PR | PATAPSCO |
| P | PATUXENT |
| PI | PIANKATANK |
| PS | POCOMOKE SOUND |
| PQ | POQUOSON |
| PO | POTOMAC |
| R | RAPPAHANNOCK |
| SA | SASSAFRASS |
| SE | SEVERN |
| S | SOUTH |
| SU | SUSQUEHANNA |
| TA | TRED AVON |
| WI | WICOMICO |
| W | WYE |
| Y | YORK |

Figure 3. Velocity and salinity ranges

(Figure 4). Several slack-water salinity sampling cruises were also available for the James, York, Rappahannock, and Potomac Rivers (Figure 4). These data provide synoptic views of maximum/minimum salinity intrusion corresponding to the concurrent tide and freshwater discharge conditions for those portions of the estuary. Wind speed and direction data were provided for varying periods of time from 24 surface weather stations (Table 1) located throughout the bay (Figure 5). Using the available 70 USGS stream-gaging stations for the Chesapeake Bay system, NAB developed a computational method to calculate daily flow records for 126 drainage basins. These basins were then consolidated into 21 strategic inflow locations to supply the estuarine model with its appropriate freshwater discharge (Figure 6).

9. Detailed descriptions of the prototype data, data collection procedures, and equipment used can be found in Appendix A. Specific periods and locations of data collection along with an assessment of data limitations are included in this appendix.

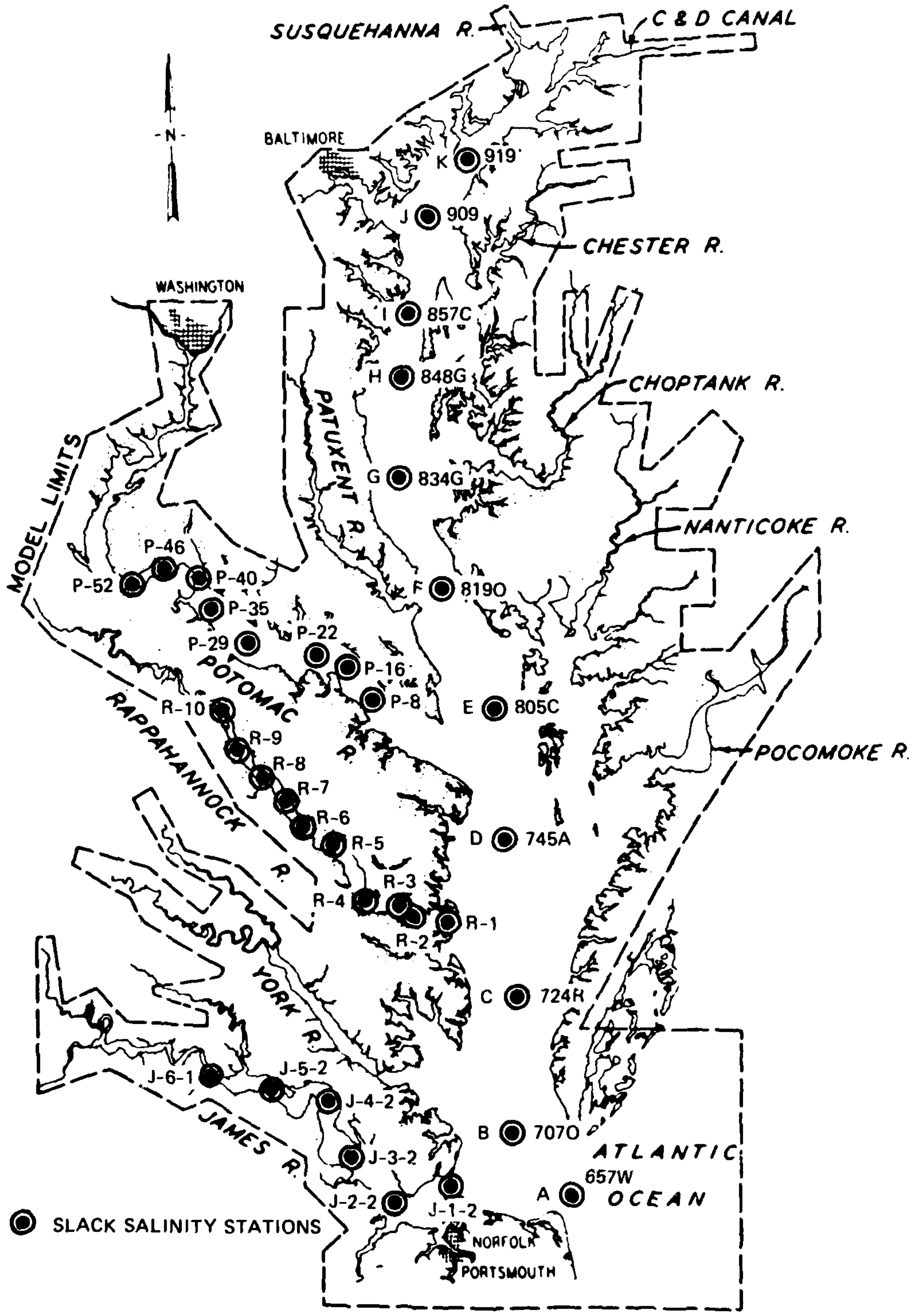



Figure 4. Slack-water salinity stations

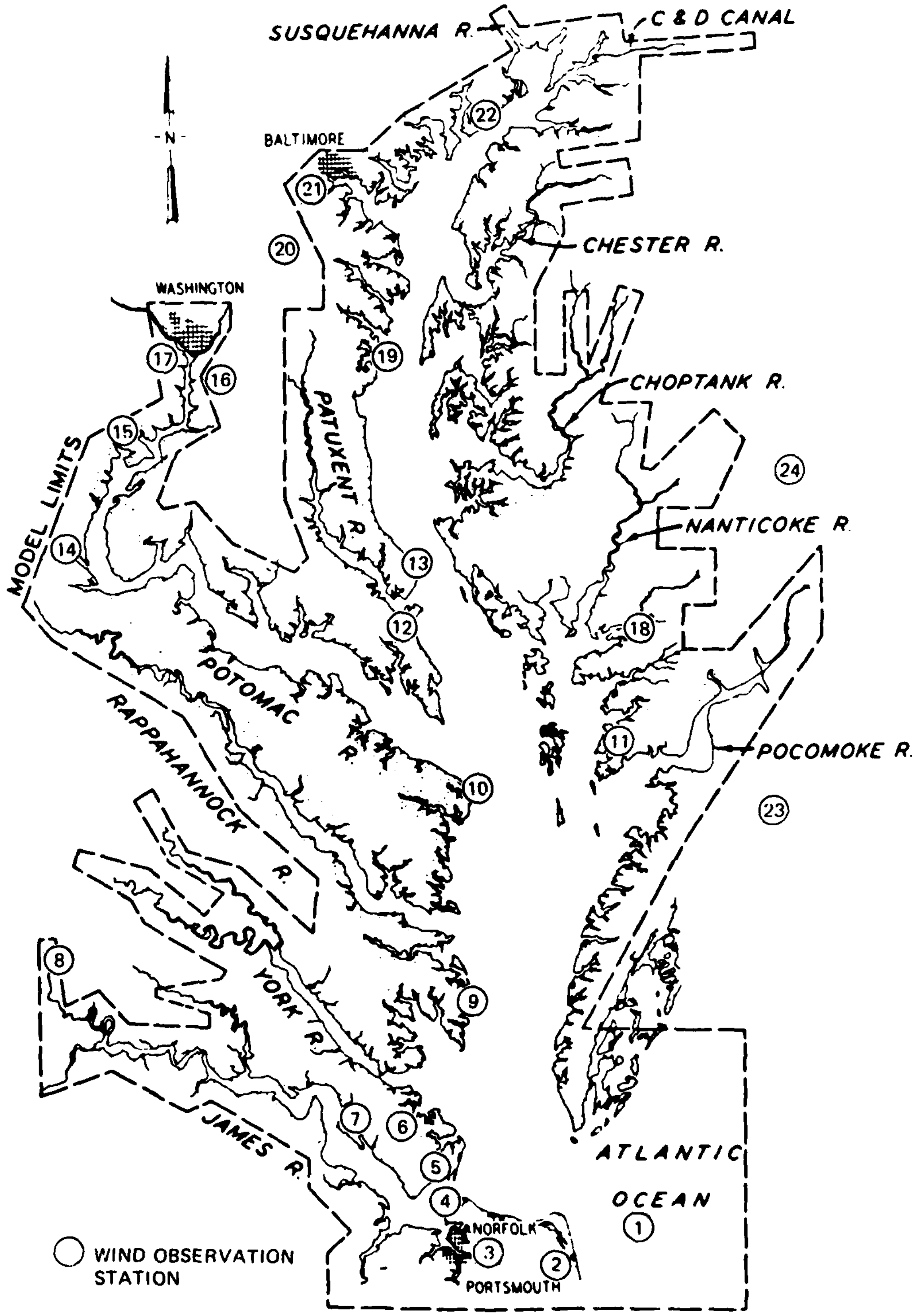



Figure 5. Weather stations

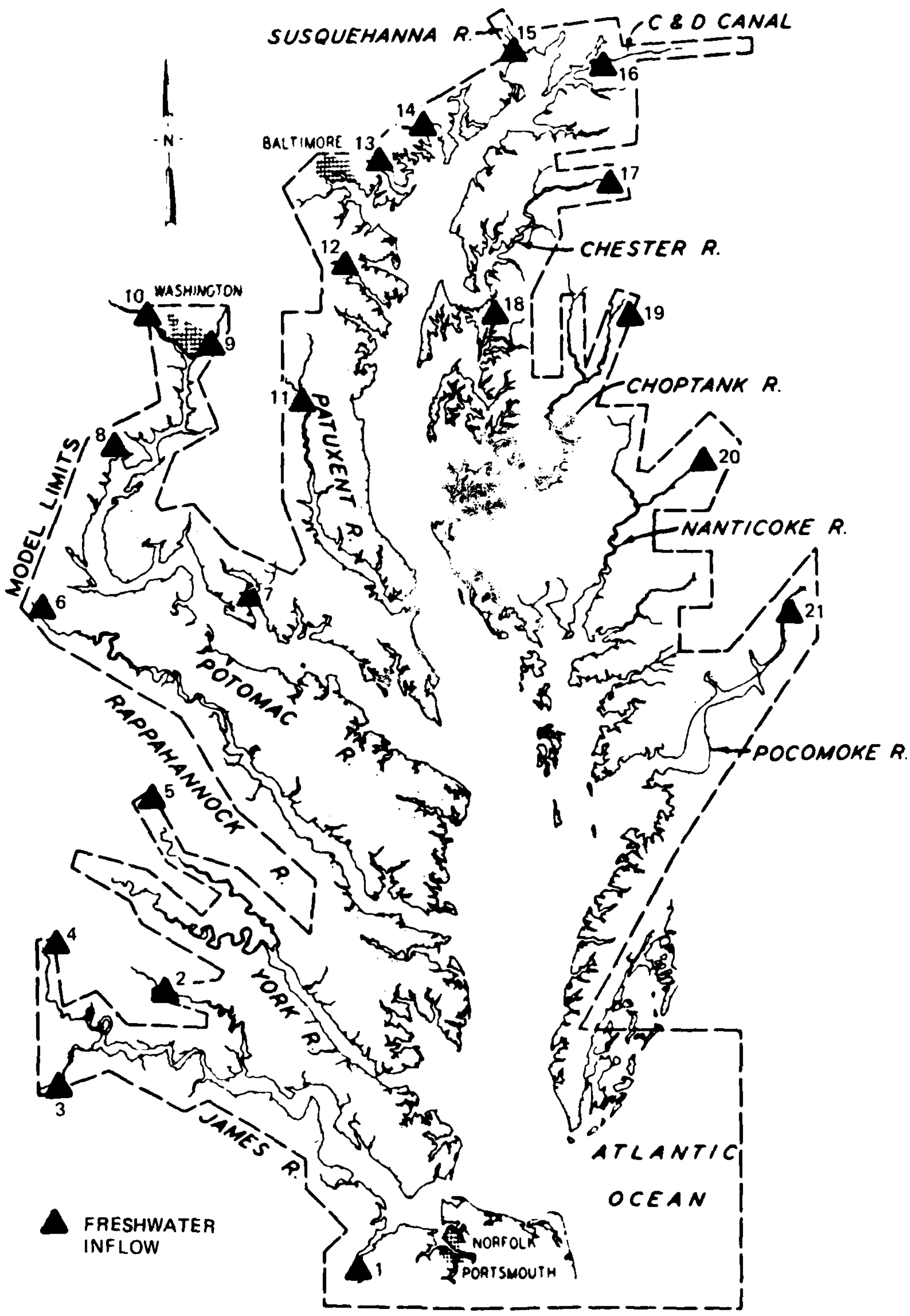



Figure 6. Freshwater inflow locations

## PART III: CHESAPEAKE BAY MODEL

### Physical Model Description

10. The physical model of Chesapeake Bay, constructed at Matapeake, Maryland, during the period October 1974-April 1976, is of the fixed-bed type molded in concrete to conform to the bathymetry of the most recent National Ocean Survey (NOS) charts at the time of construction (Coast and Geodetic Survey prior to 1970). The model covers approximately 8.6 acres and is completely housed in a 14-acre building for protection from the elements. The building is approximately 1000 ft long and 600 ft wide. The molded area of the model extends from offshore in the Atlantic Ocean to the head of tide for all tributaries emptying into Chesapeake Bay. The entire length of the Chesapeake and Delaware (C&D) Canal extending to Delaware Bay is also modeled. Model reproduction extends to the +20 ft contour based on water levels shown on USGS quadrangle maps.

11. The hydraulic model was based on the equality of model and prototype Froude numbers reflecting similitude of gravitational effects as opposed to viscous effects (Reynolds number model). Geometric scales of the model are 1:1000 horizontally and 1:100 vertically, reflecting a scale distortion of 10:1. For distorted-scale models, the characteristic length is that of the vertical dimension. Therefore, the Froude number is defined as:

$$F_n = \frac{V}{\sqrt{gD}} \qquad (1)$$

The following scales are determined by use of geometric relations and Froudian model laws:

| Characteristic | Ratio |
|---|---|
| Vertical length | $D_r = 1:100$ |
| Horizontal length | $L_r = 1:1000$ |
| Time | $T_r = L_r/\sqrt{D_r} = 1:100$ |

(Continued)

| Characteristic | Ratio |
| --- | --- |
| Velocity | $V_r = \sqrt{D_r} = 1:10$ |
| Discharge | $Q_r = V_r A_r = L_r \sqrt{D_r^3} = 1:1,000,000$ |
| Volume | $L_r^2 D_r = 1:100,000,000$ |
| Slope | $D_r/L_r = 10:1$ |

As in most estuary models, the salinity (density) ratio is unity. Additional bottom roughness is required in distorted-scale models to ensure that the flow regime remains turbulent so that the proper reproduction of tidal heights, tidal velocities, and salinity distributions can be achieved. In relatively deep areas (greater than about 10 ft), additional roughness is simulated in the model by embedding stainless steel strips in the model floor. The preliminary distribution of these strips was calculated as a function of depth using conservation of linear momentum considerations.* Based on these calculations, over 700,000 1/2-in.-wide roughness strips were placed in the model. Final distribution was then obtained by trial and error by systematically bending up or bending down these strips until proper amplitude and phasing of tidal heights and velocities were obtained. In shallow-water areas, the additional roughness was achieved by scratching the concrete surface before it set during model construction.

## Model Appurtenances

12. The model was designed to include all necessary appurtenances for the reproduction of prototype boundary conditions and the measurement of the model response to those boundary conditions. An additional capability of the model complex was the ability to operate as a completely self-contained unit. The appurtenances necessary to achieve these goals include both manual and computerized model control and data-gathering

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* R. H. Multer. (Unpublished memorandum.) "Distribution of Model Roughness Strips," on file at the U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

capabilities in addition to a complete water supply, treatment, and storage system. Backup emergency power generation and uninterruptible power system capabilities were provided so that continuous operation of the model could be ensured. Laboratory facilities were provided for in-house analysis of salinity and dye dispersion studies. The primary appurtenances of the model are described below.

Computer facilities

13. The system configuration available for model control and data analysis is as follows:

- a. One minicomputer (TI 960) with 64K, 16-bit words of memory, is devoted to model control (freshwater inflow and primary and secondary tide generation) and data acquisition (water-level detectors, tide generators, and inflow monitoring). Complete control of the model is possible by the inclusion of two interval timers in the computer. The first timer is used by the computer operating system while the second controls the strobe system (to be described later).
- b. One minicomputer (TI 980) with 56K, 16-bit words of memory, is devoted exclusively to data reduction and data management.
- c. One moving head (Sykes) disk for mass storage supports either computer system and has a capacity of 2.5 million 8-bit bytes.
- d. One 9-track, 800 BPI magnetic tape drive is used exclusively for data reduction and data management.
- e. One 300 card-per-minute card reader supports either computer system.
- f. One electrostatic printer/plotter supports either computer system. The 11-in. output has a printing capability of 300 lines per minute and a plotting resolution of 100 points per inch.
- g. Two electronic data terminals equipped with dual cassette transports can be used for communication with either minicomputer or with other computer systems.
- h. One acoustical coupler provides data transmission between the data terminals and other computer systems.
- i. Two flexible disk storage devices (floppies), each with a capacity of 250K bytes, support either computer.
- j. One card punch with interpreting capabilities supports both computers.

k. Canned and specifically designed software routines provide support of total model operations.

14. An uninterruptible power supply system was included to ensure continuous computer control during power fluctuations and outages. Alternating current (AC), either from commercial power or the emergency generator, is diverted into a battery charger where it is converted into 50 volts direct current (VDC). This current, either directly or from an array of charged batteries, is supplied through a transformer switch to an inverter where the 50 VDC is converted to 110 VAC to service the computer. The system monitors the power output, the battery supply, and the auxiliary AC power, making automatic transfers when necessary. Proper AC phasing (60 Hz) is preserved so continuous, homogeneous power is assured for computer operations at all times.

SERDEX system

15. Model control and data acquisition by the minicomputer are made possible by a multiple-loop, multiple-rank, two-way data transmission. The system developed uses a current-loop technique in which serial ASCII (American Standard Code for Information Interchange) data are transmitted between the minicomputer and the various model devices over a twisted pair cable. The method of transmission was designed to minimize signal distortion and time skewing of data due to the long cable lengths associated with the model. This serial data exchange system (SERDEX) is managed by a hierarchical software package developed specifically for the Chesapeake Bay model configuration. The primary components of the system are 1 computer multiplexer (master MUX), 9 model multiplexers (MUX's), 33 transmitters, and 23 receivers. A schematic diagram of the system is shown in Figure 7.

16. The minicomputer is linked to the master MUX through a fully duplexed current loop. Five half-duplex current loops connect the master MUX with the model MUX's. Each model MUX can be connected by half-duplex current loops to an additional MUX and/or to model sensors and control devices. A total of eight outputs are possible from each MUX so that a cascading of MUX's can result in an almost unlimited expansion of the number of model sensors and control devices. Timing and computer memory

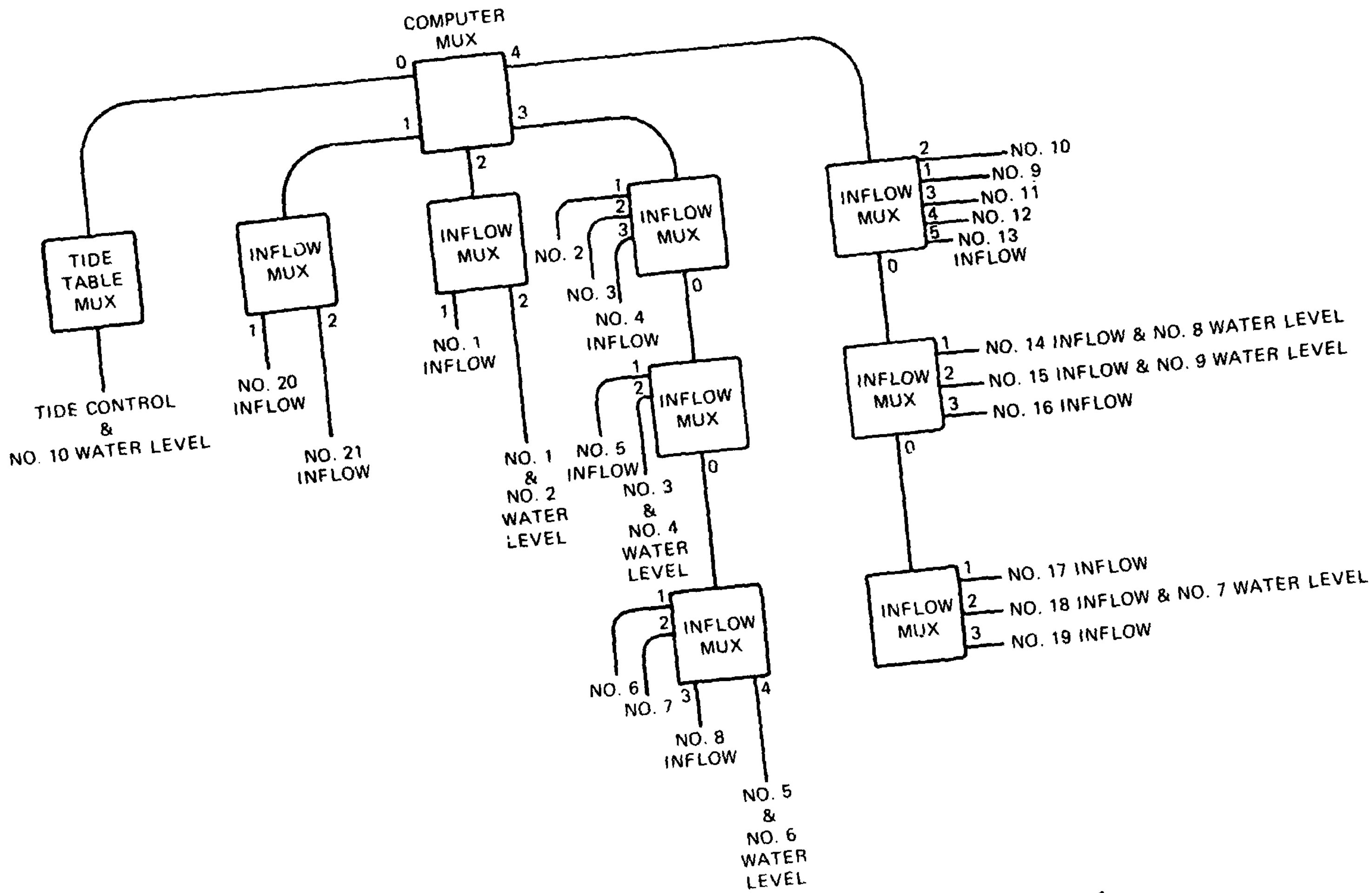



Figure 7. SERDEX block diagram for Chesapeake Bay model

considerations, however, place a practical limit on this expansion.

17. Each model sensor or control device is associated with either a transmitter or a transmitter/receiver combination. Each transmitter accepts parallel BCD (binary coded decimal) either directly from a model sensor or through an analog-to-digital (A-D) converter. This signal is converted to serial ASCII for transmission to the computer. Each model receiver accepts serial ASCII from the computer and converts the signal to parallel BCD. This signal either directly controls some digital device or is further converted to an analog signal (by means of a digital-to-analog (D-A) converter) to control an analog device. All transmitting and receiving sequences are synchronized by a system of electrical pulses or strobes.

18. The strobe is a short duration pulse sent at discrete programmable intervals and is used to synchronize the receiving and transmitting of data. Two separate strobe circuits are incorporated into the system. Strobe No. 2 synchronizes the tide generators while strobe No. 1 synchronizes all additional data conversions. Each strobe is independently time programmable. Time increments used are 36 sec for strobe No. 1 and 1.5 sec for strobe No. 2. The sequencing used to achieve the simultaneous sampling of data from the model sensors for transmission to the computer is (a) receiver receives data, (b) strobe from the computer and hold data, and (c) transmit data to the computer when addressed. This sample-hold-transmit procedure eliminates the time skew problems normally associated with large physical distances. Controlling data (inflows and tide generator data) employ only the first two sequences since it is not necessary to transmit controlling data back to the computer.

19. The above-described system enables complete programmable computer control of the tide generators and freshwater inflow devices and provides monitoring capabilities for all automated devices on the model. Monitored data may be transmitted to a data terminal for immediate review (visual) to ensure proper model control and response and/or stored on flexible disks for later data reduction and management.

Freshwater inflow control system

20. Programmable freshwater inflow control devi es capable of reproducing variable hydrographs are located at 21 strategically selected inflow points on the model. Each inflow control unit consists of a pressure regulator, a digital flow control valve, and a flowmeter (Figure 8). A mechanical spring-type pressure regulator ensures constant pressure to the digital flow control valve. Each digital valve contains eight solenoid valve actuators associated with a binary addressable progression of orifice openings. A total of 256 discrete flow rates may be obtained for each valve by energizing different combinations of solenoid valves. In general, two size ranges of digital valves are used to produce a flow range of 0.01 to 155 gpm. Two types of flowmeters are used to measure this range of discharge.

21. Small discharges (0.01 to 2.0 gpm) are metered by bearingless type flowmeters in which a jet of water enters a metering chamber tangentially and spins a small circular disk. Light reflective marks on the disk are sensed by a photo detector which produces electrical pulses. Through calibration, the frequency of this pulse measures the flow through the chamber. A four-digit BCD counter card counts the number of pulses between strobes. This is converted to serial ASCII by the transmitter and transmitted to the computer.

22. Larger discharges (2 to 155 gpm) are metered by a venturi-type fluidic metering device whose body acts as a fluidic oscillator. The frequency of oscillation is proportional to the flow rate through the meter. A flush-mounted sensor detects these oscillations and converts the signal to a voltage. This voltage is measured by a voltmeter, converted to BCD, and then converted to serial ASCII for transmission to the computer.

23. The computerized process control system activates the prescribed solenoid valves at the appropriate times and checks for errors between the flowmeter feedback signal and the desired digital valve input. If the desired flow is not achieved, the solenoid valves may be manually adjusted. In the future, programming will enable a feedback loop to automatically adjust the solenoid valves to achieve the desired flows.

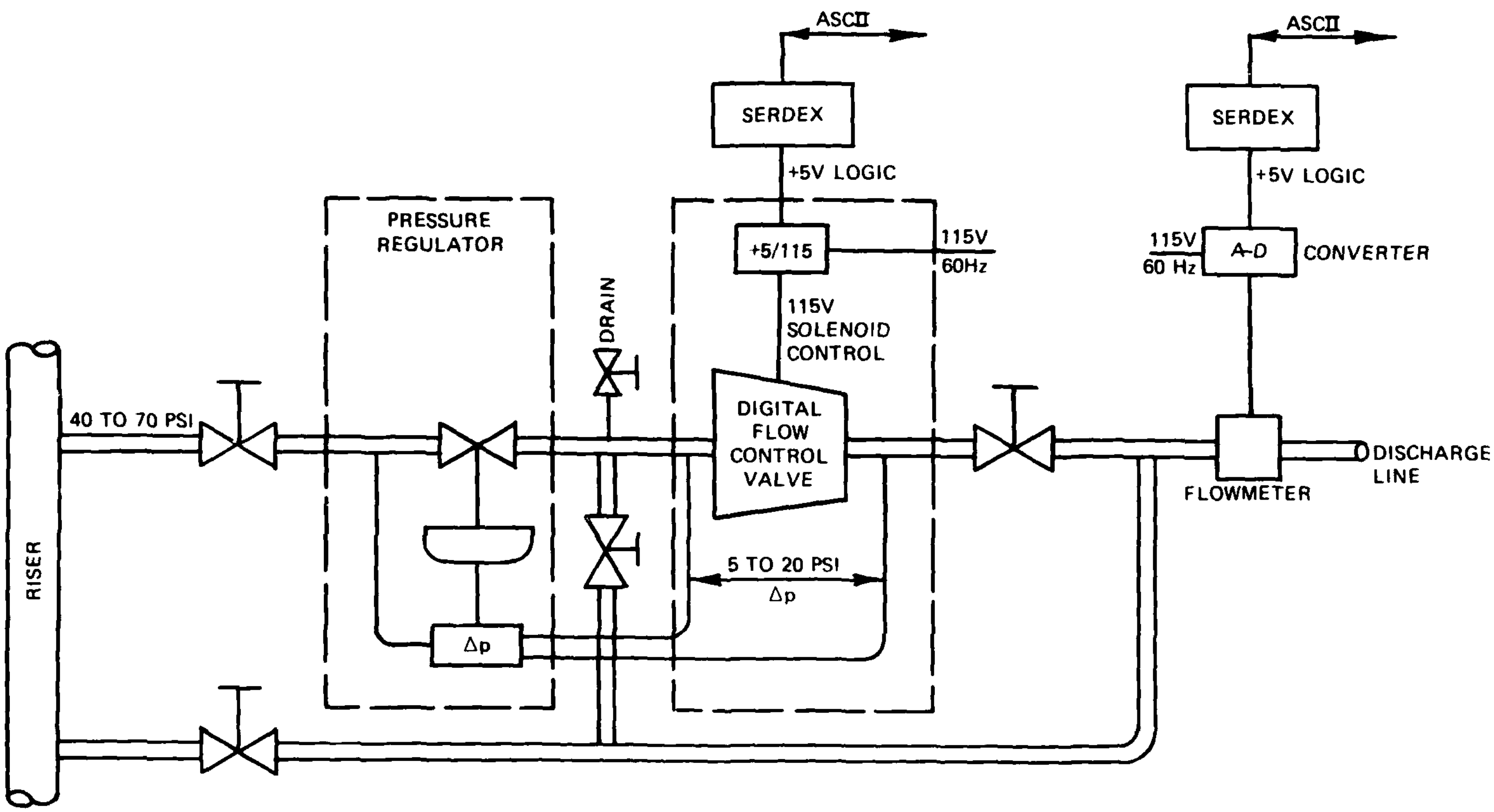



Figure 8. Inflow control system function diagram

For backup support, a manual bypass is also provided at each inflow point. Figure 8 is a schematic diagram of an inflow device.

Water supply,
treatment, and storage

24. All water utilized in the model is supplied by two deep wells with discharge capabilities of 250 and 500 gpm. Water storage is provided by a 500,000-gal elevated storage tank. A complete water treatment plant can supply an average flow of 400 gpm indefinitely, or a flow of 1250 gpm for an 8-hr period of operation. The primary trunk lines can carry a total discharge equivalent to double the maximum flow of record for the Susquehanna River, plus the maximum flows of record for all other tributaries. This flow amounts to 1661 gpm. Minimum pressure is 50 psig.

Tide generators

25. Tides in the model are reproduced by a primary tide generator in the model ocean and a secondary tide generator at the eastern end of the C&D Canal. Both generators are capable of either computer control or manual control. Under computer control, serial ASCII tide elevation data are transmitted from the computer to the tide control receivers. These data are converted to parallel BCD and further converted through a D-A converter to a voltage. This voltage changes the position of the shaft of a pneumatic pressure-sensing bubble-tube positioner (which indicates the actual model water level) by use of a servomotor. The change in shaft position changes the back pressure on the bubble-tube positioner, thus indicating an error between the actual and desired model water levels. These pressure changes are used by the pilot regulator to adjust the rolling gates on the inflow-outflow system (which control the water-level elevation of the headbay area), thereby generating the tide. This system provides the capability of simulating any desired tide sequence including, but not limited to, a lunar month of variable tides producing both neap and spring variations. The length of the desired control tide signal is only limited by the storage capacity of the computer. Under manual control, a repetitive 24.84-hr tidal

cycle is produced by the rotation of a cam constructed to represent the elevation changes for a predetermined tidal cycle. Movement of the cam activates a potentiometer that produces the voltages used to change the position of the shaft of the bubble-tube positioner. A repetitive tide is therefore produced in a fashion similar to the computer-controlled tide.

26. In more physical detail, the primary tide generator consists of a gravity inflow-gravity outflow system containing a return sump (160 by 60 by 11 ft) at a minus elevation (relative to the model ocean), a supply sump (72 by 60 by 15 ft) at a positive elevation fed by a 20-cfs pump from the return sump, and a headbay area (211 by 20 by 8 ft) varying about a mean level. Two rolling gates, connecting the headbay area with both the supply and return sumps, operate simultaneously to achieve the desired headbay elevation, thereby generating the desired ocean tide. A continuous circulation between the three areas helps maintain a desired source salinity. The operation of the primary tide generator and a schematic drawing of its operation are shown in Figure 9. The secondary tide generator is much smaller but operates on the same general principle.

<u>Saltwater supply system</u>

27. Constant ocean salinity is assured by maintaining a prescribed concentration of the source salinity in the supply sump. Saturated brine (315-320 ppt) is obtained by mixing granular salt (NaCl) and water in a 35- by 30- by 15-ft storage sump. The brine is mixed with the model solution in the return sump to obtain a desired salinity. This well-mixed solution is then pumped to the supply sump for input to the model.

<u>Skimming weirs</u>

28. A low salinity (brackish) accumulation in the surface layer of the model ocean will develop due to the constant addition of fresh water at the inflow locations. In order to maintain the model ocean at a constant salinity and at the proper water-level elevation, this brackish water lens must be removed and disposed of. This operation is performed by the use of skimming weirs which are adjusted to draw off a discharge equal to the total freshwater inflow into the model. The operation of the skimming weirs and a schematic drawing are shown in Figure 10.

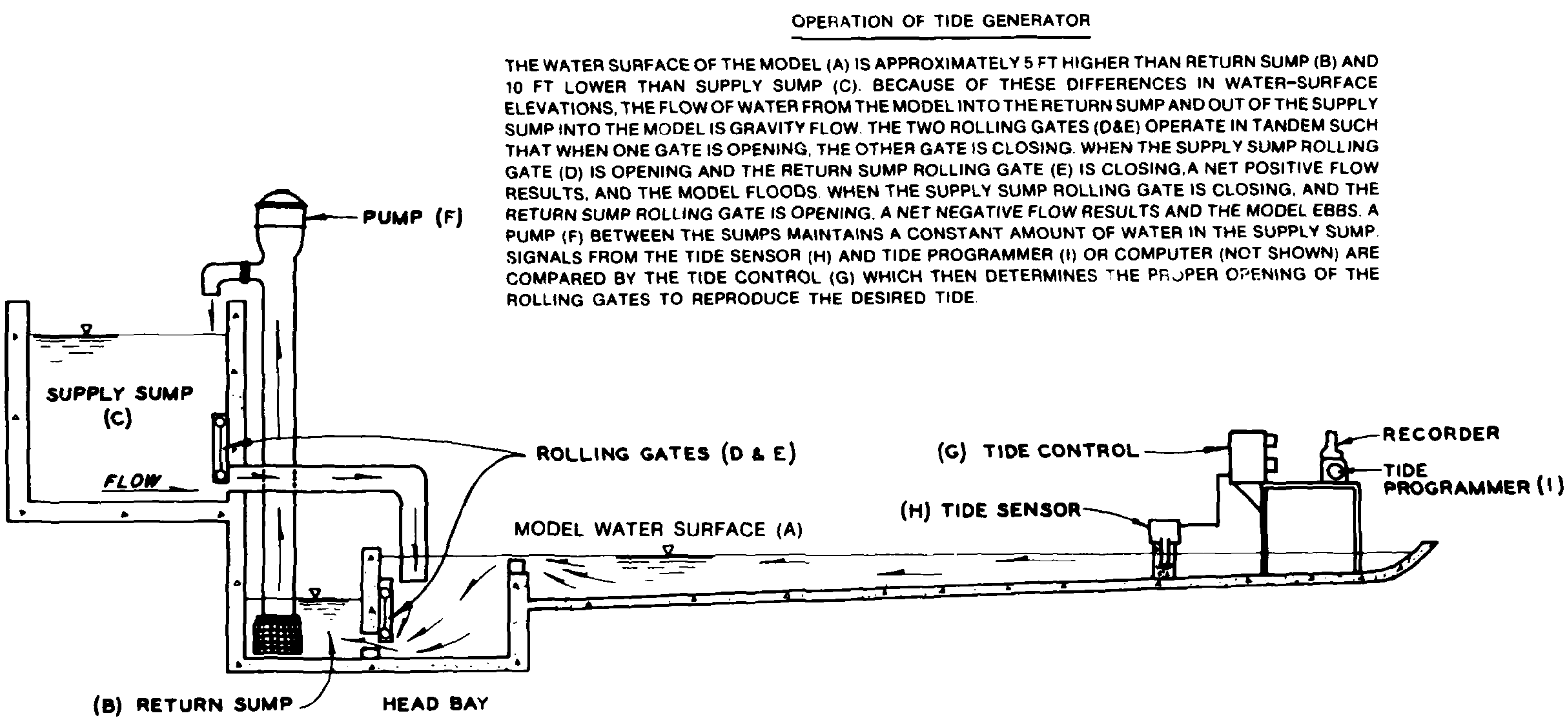



Figure 9. Primary tide generator

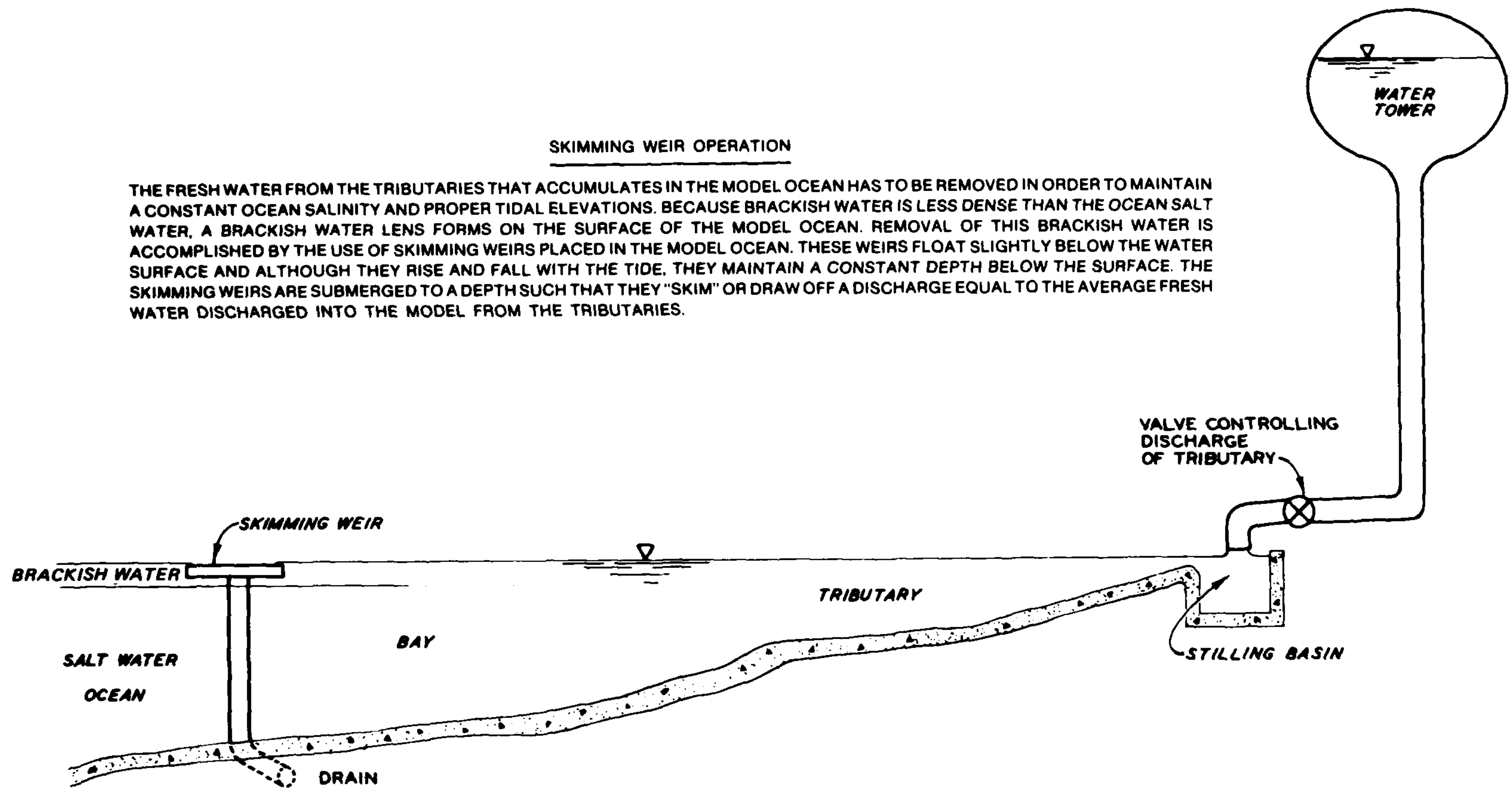



Figure 10. Skimming weir operation

Mixing weirs

29. The mixing weir system consists of five vertical 6-in.-diam risers submerged just below the ocean surface. These weirs, located bayward of the headbay, ensure proper mixing of the ocean water. Water drawn off by the mixing weir is gravity-fed back to the return sump, remixed with the salt water, and returned to the model ocean via the supply sump. Without the mixing weir, brackish water that was not drawn off by the skimming weirs would dilute the ocean and hinder the maintenance of the correct ocean salinity.

Induced mixing bubbler system

30. A bubbler system was installed in the model to provide additional vertical mixing. The need for this capability will be described later in this report. The system consisted of a compressor supplying air to perforated Tygon tubing placed along the axis of the bay and major tributaries. Single lines extended up the tributaries with perforations at approximately 12-ft intervals. The main bay configuration approximated a 12-ft perforation grid. Figure 11 shows the locations of the Tygon tubing in the model.

Tide gages

31. Permanently mounted point gages were installed in the model to correspond to the 75 prototype tide stations shown in Figure 2. These gages, graduated to 0.001 ft (0.1 ft prototype), are used for the manual measurement of tidal elevations. A typical point gage is shown in Figure 12.

Water-level detectors

32. Ten high-precision water-level measuring instruments were designed and built at WES for the Chesapeake Bay model. Specifications for these units are displacement range 0.5 ft, accuracy 0.003 in., resolution 0.005 in., and temperature range 32-110°F. Commercial units were not available that met these specifications.

33. The sensors are basically an air capacitance system consisting of a stainless-steel probe, a closed loop servosystem, and a capacitance transducer to convert a specified distance (the air gap between the probe and the water surface) into a d-c voltage. This voltage, in

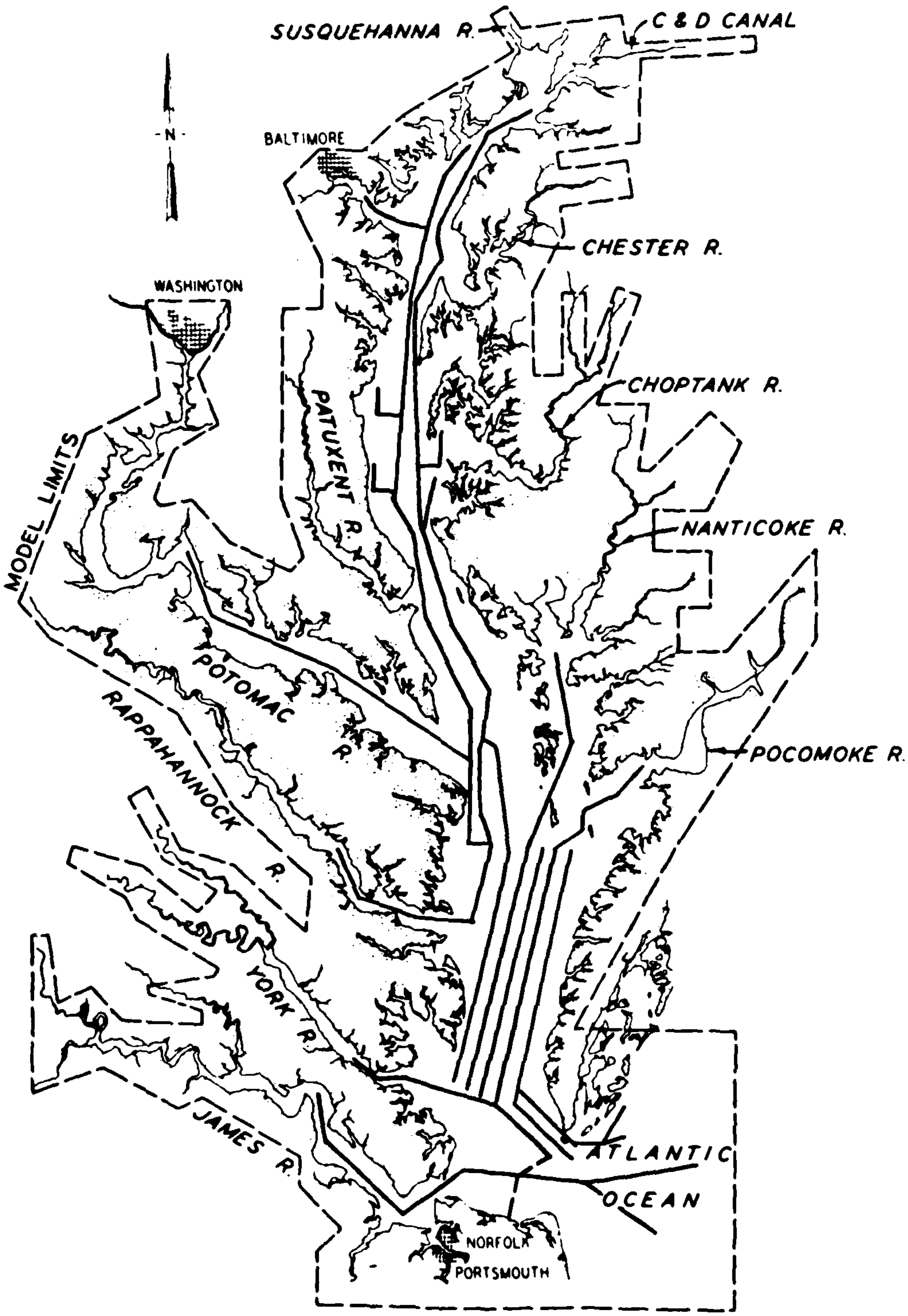



Figure 11. Bubbler system

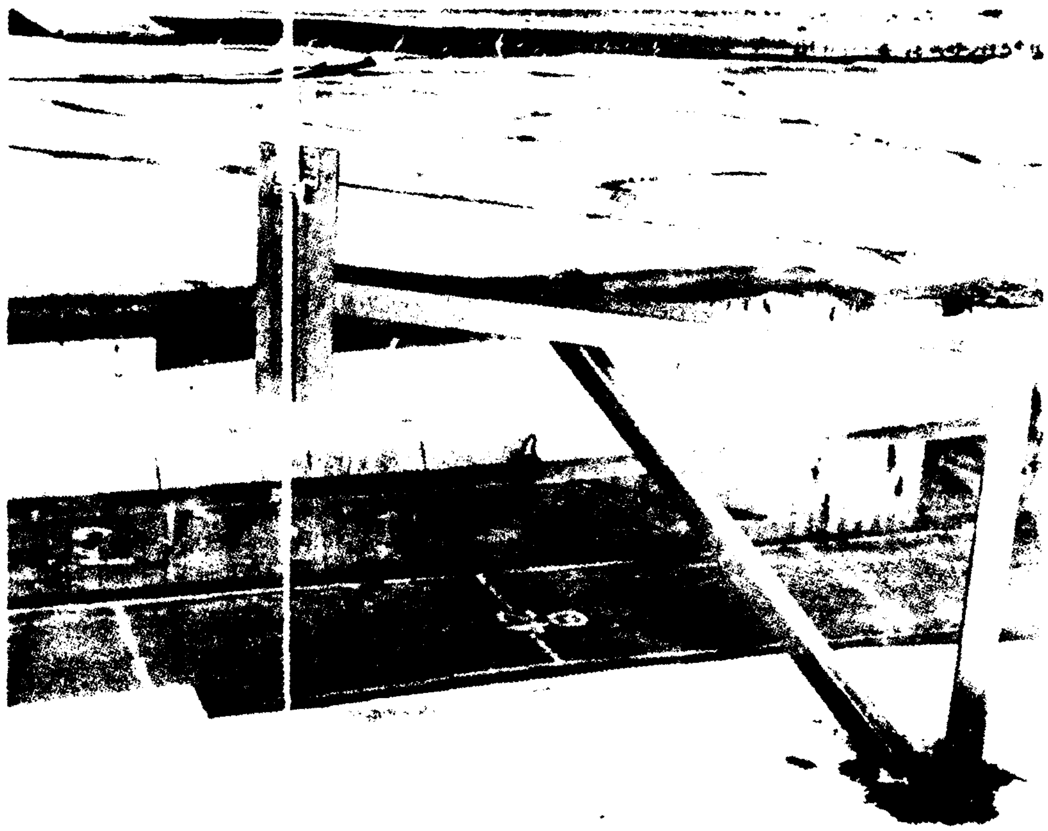


Figure 12. Permanently mounted point gage

conjunction with the servosystem, maintains a constant air gap. The servomechanism uses a precision slide table with a stepping motor. The movement of the slide table and probe are measured by a potentiometer to produce an analog voltage. This voltage is converted to BCD and further converted to serial ASCII for transmission to the computer. This noncontacting sensor technique provides high quality data with minimum maintenance and calibration. A schematic diagram of the system is shown in Figure 13.

Current velocity meters

34. Current velocity measurements were made in the model using miniature Price-type current meters (Figure 14). The center line of the five cups was about 0.045 ft above the bottom of the meter frame;

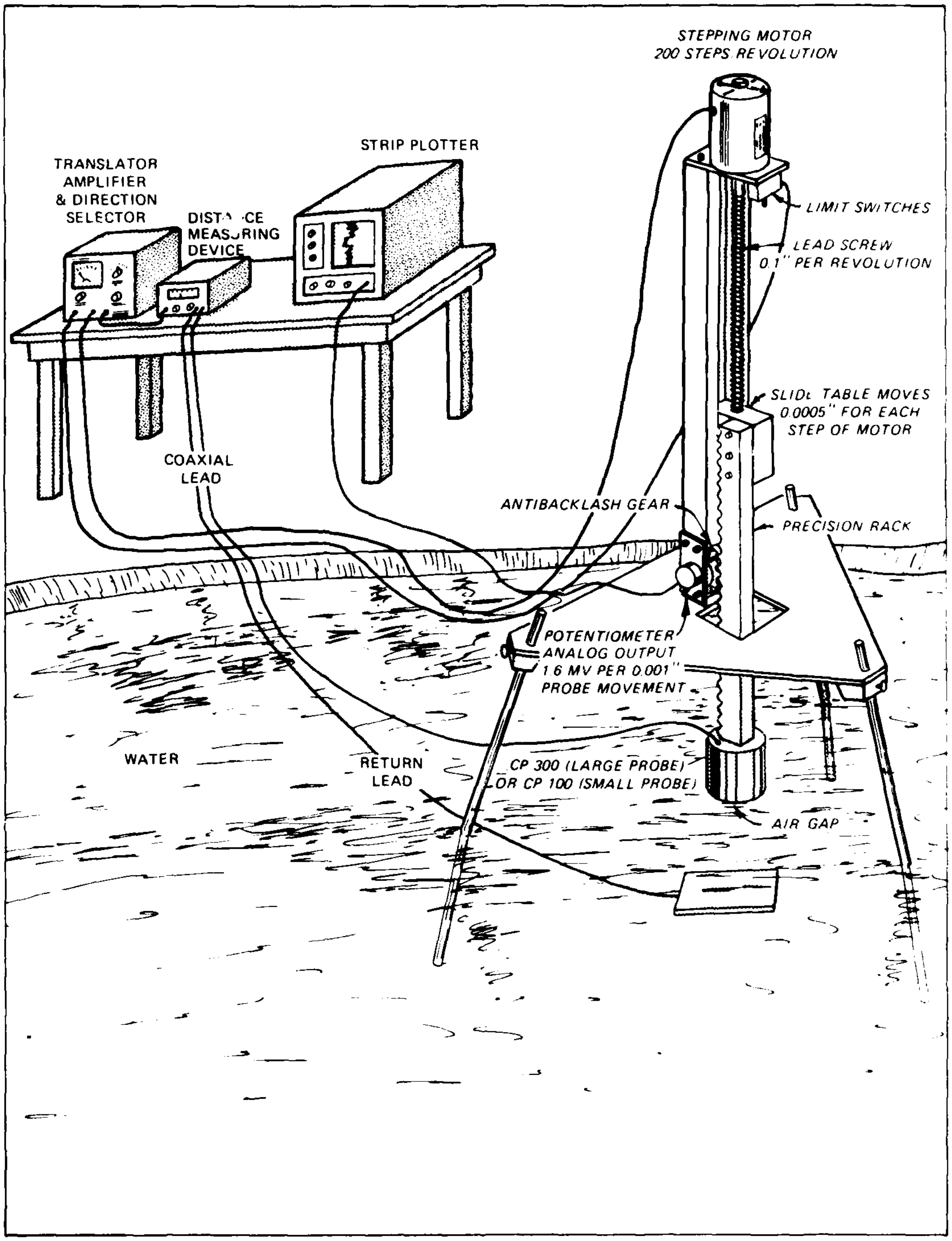



Figure 13. Water-level detecting instrument

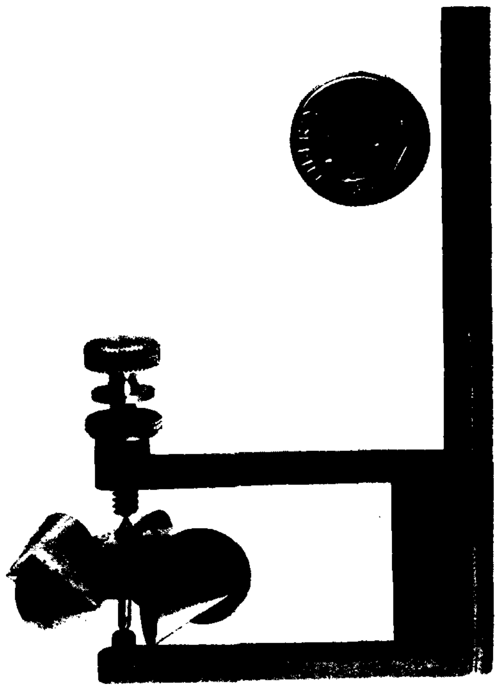


Figure 14. Miniature Price-type current meter

therefore, bottom velocities in the model were measured about 4.5 ft (prototype) above the bottom. The width of the meter, about 0.1 ft in the model, represented a horizontal width of about 100 ft in the prototype. The height of the meter cups, about 0.04 ft, represented about 4.0 ft in the prototype. The distortion of area (model to prototype) resulted in comparing model velocities averaged over a much larger area than the prototype point observations. Velocities were obtained by counting the number of revolutions the meter wheel made in a 10-sec interval (about 17 min in the prototype). The meters were calibrated frequently to ensure an accuracy of ±0.05 fps (0.5 fps prototype).

Vacuum sampling system

35. The vacuum sampling system consists of three independent vacuum systems, each designed to sample approximately one-third of the model's 199 collection stations. Each system has a separate pipe network constructed of 1/2-in.-ID polybutylene tubing attached to the shelter trusses. From tees on the 1/2-in.-ID polybutylene tubing, located

over each of the model's collection stations, 1/4-in.-ID polybutylene tubing extends down to the model surface. The vacuum line branches into collection jars located on stands at each station. From each jar, a 1/16-in. vacuum line branches into a sample test tube. A 1/16-in. vacuum line then extends down to a brass tube which has a port placed at the desired sample depth from each test tube. Samples are drawn off by activating the vacuum system at the selected times required for each specific model test. Following the completion of sampling, test tubes are brought to the laboratory for salinity analysis and dye concentration (if required).

Salinity meters

36. Electronic conductivity meters (Balsbaugh 1210 and Beckman RI55) monitored in situ salinity concentrations at specific points on the model and in the supply and return sumps. Beckman RA5 Solumeters (Figure 15) were used for laboratory analysis of samples withdrawn from the model. The Balsbaugh meters employ an oscillator-detector circuit while the Beckman meters employ a Wheatstone Bridge circuit for conductivity measurements.

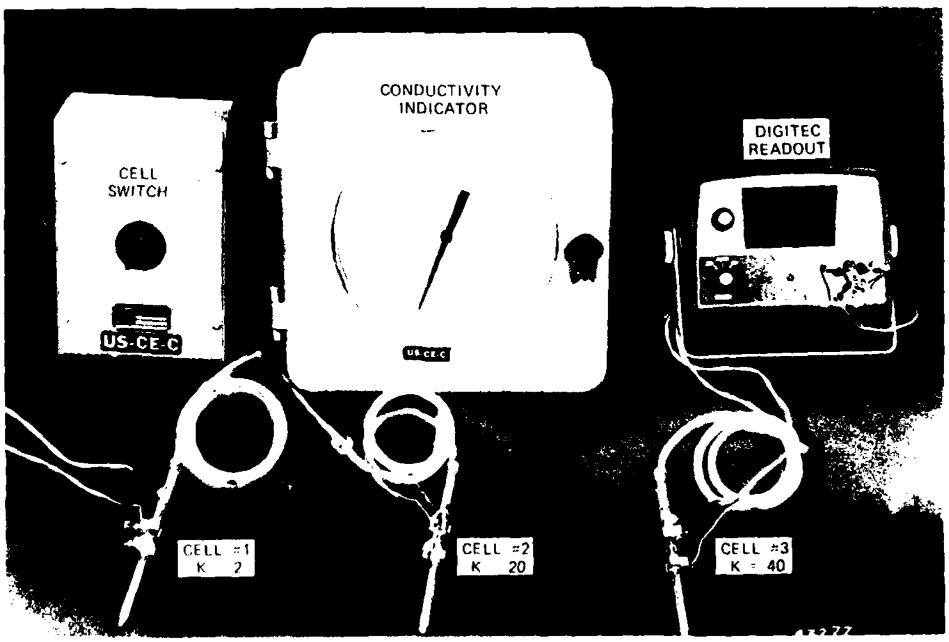



Figure 15. Salinity meter

## PART IV: PROTOTYPE DATA ANALYSIS

### Introduction

37. A detailed prototype data analysis program was conducted to provide additional insight and understanding of the hydrodynamics of Chesapeake Bay. The need for this effort was recognized for the following three reasons:

- a. The nonsynoptic nature of the prototype data collected for the bay made conventional verification schemes impossible.
- b. Prototype tidal height data from the ocean station were not obtained.
- c. Energy at nonastronomical periods was identified which constituted a substantial portion of the total tidal energy of the bay. This nonastronomical energy was first noticed as low reduction in variance (RV) values resulting from 1-year harmonic analysis on a variety of tidal stations in the Chesapeake Bay. It was also evidenced as unusually high cospectral density function values at low frequencies (on the order of 100 hr) shown in a Chester River report published by the State of Maryland and Westinghouse Electric Corporation (Clarke and Palmer 1972).

38. The difficulties posed by the nonastronomical energy in the bay relate directly to the method of verification. For example, what is the origin of the energy and can it be reproduced by the model tide generator? These questions had to be answered before a reliable verification procedure could be formulated. In order to answer these questions, both the astronomical and nonastronomical tidal components were analyzed.

### Linearity of the Bay

39. The first phase of analysis was to determine the degree of linearity of the bay with respect to the propagation of shallow-water waves. This was performed to determine if tidal and nontidal energy could be satisfactorily reproduced in the model. Twelve representative tidal stations along the main portion of the bay, with synoptic data for August 1972, were selected for detailed analysis.

40. Fast Fourier Transforms (FFT's) were applied to 1024 points (1/2-hr time increments) for each of the 12 tide records. Figure 16 shows a typical FFT for sta 59. Resulting phase angles for the diurnal and semidiurnal periods were plotted versus distance up the bay (Figure 17). Resulting linear relationships show that the primary astronomical waves propagate at a relatively constant speed, consistent with linear wave theory for shallow-water waves and essentially constant depth. These results confirm that the primary tidal constituents can be reproduced by the model tide generator and are not affected, or not significantly so, by the low frequency nonastronomical component of the records.

41. A similar procedure was applied to the nonastronomical portion of the tidal records. Low frequencies of 0.0098 and 0.0078 cycles per hour (periods of 102 and 128 hr), associated with high-energy levels, were selected for analysis. These phase angles were similarly plotted versus distance up the bay. Resulting plots, shown in Figure 18, indicate two separate portions: a flat portion indicating no propagation velocity and an upward sloping portion. The sloping portion does indicate a propagating velocity; however, it does not travel at a velocity consistent with that of a shallow-water gravity wave. The conclusion of this preliminary analysis was that the low-frequency wave present in the bay system could not be duplicated in the model by the tide generator. For this reason, the source of the low-frequency energy was investigated by detailed analysis of meteorological data (wind fields).

## Low-Frequency Energy

42. A 24-point symmetric, nonrecursive, low pass filter was developed to isolate the low-frequency portion of the data for analysis. The filter was designed to separate the time series of data into an astronomical portion with a period of less than 36 hr and a nonastronomical portion with a period of greater than 36 hr.

43. A brief description of the filter will be made to distinguish it from other types of filters commonly in use. Development of the filter was based on the use of the Fourier expansion coefficients for an

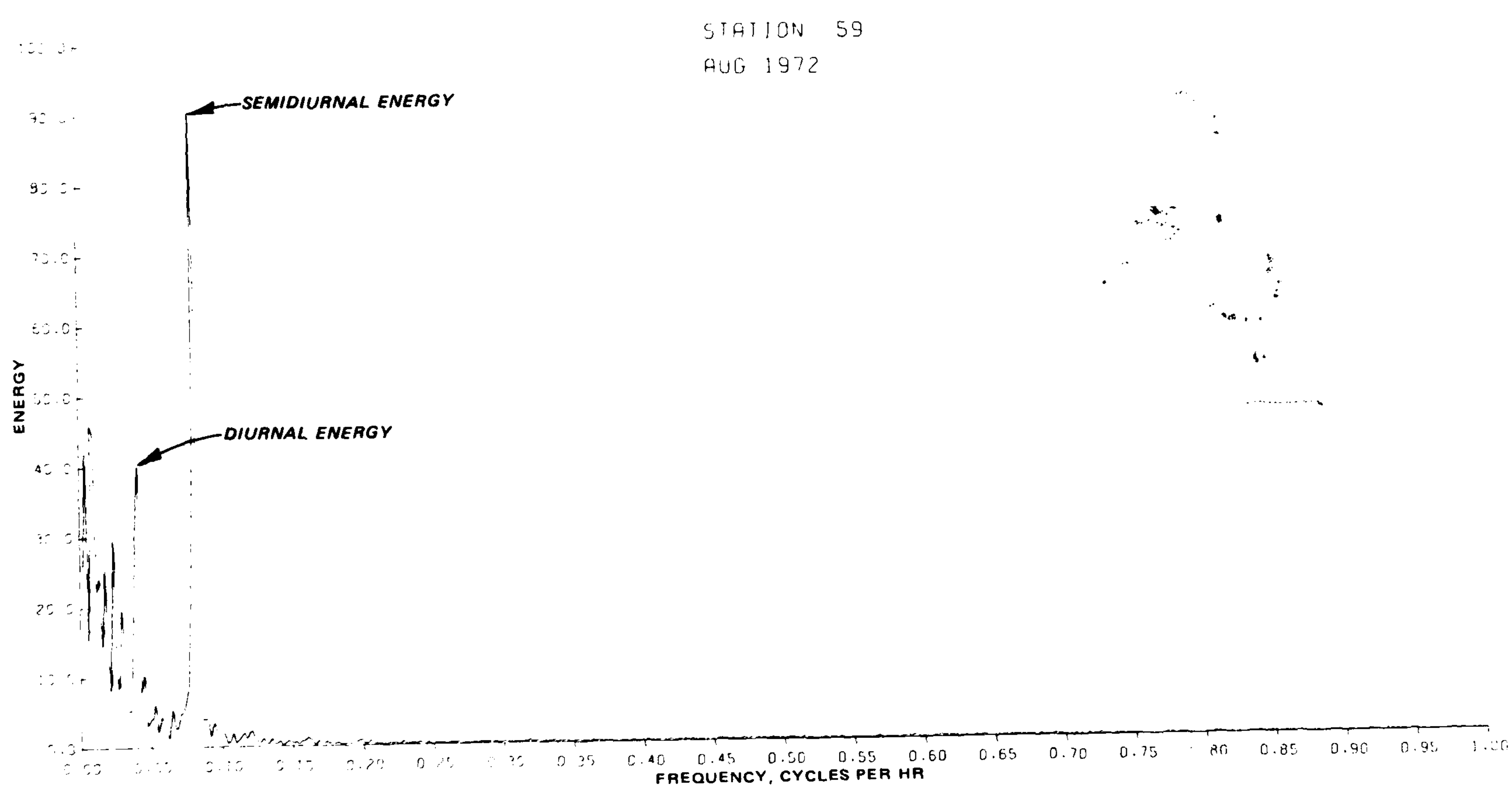



Figure 16. Tidal height energy spectrum

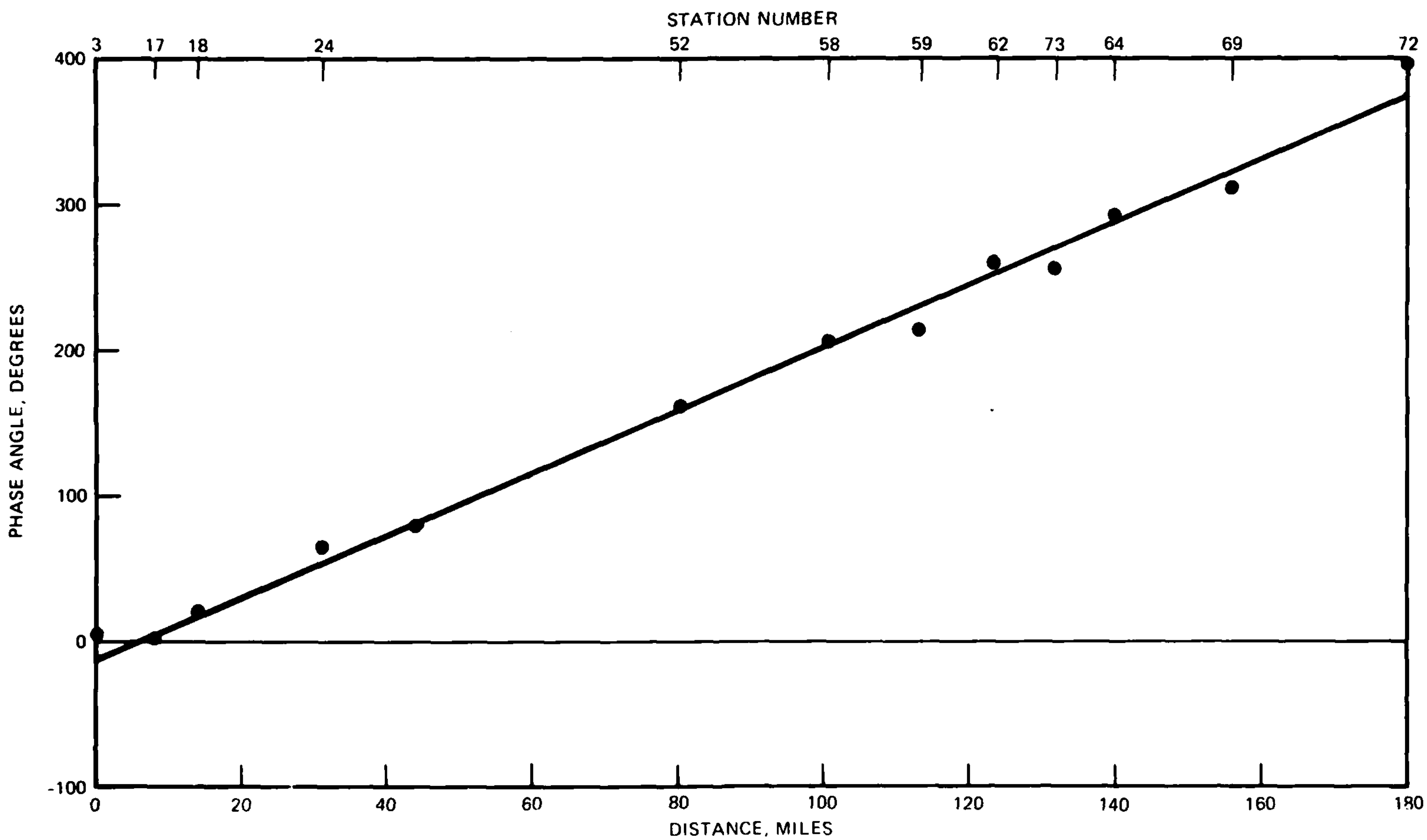



Figure 17. Phase angle at diurnal and semidiurnal frequencies

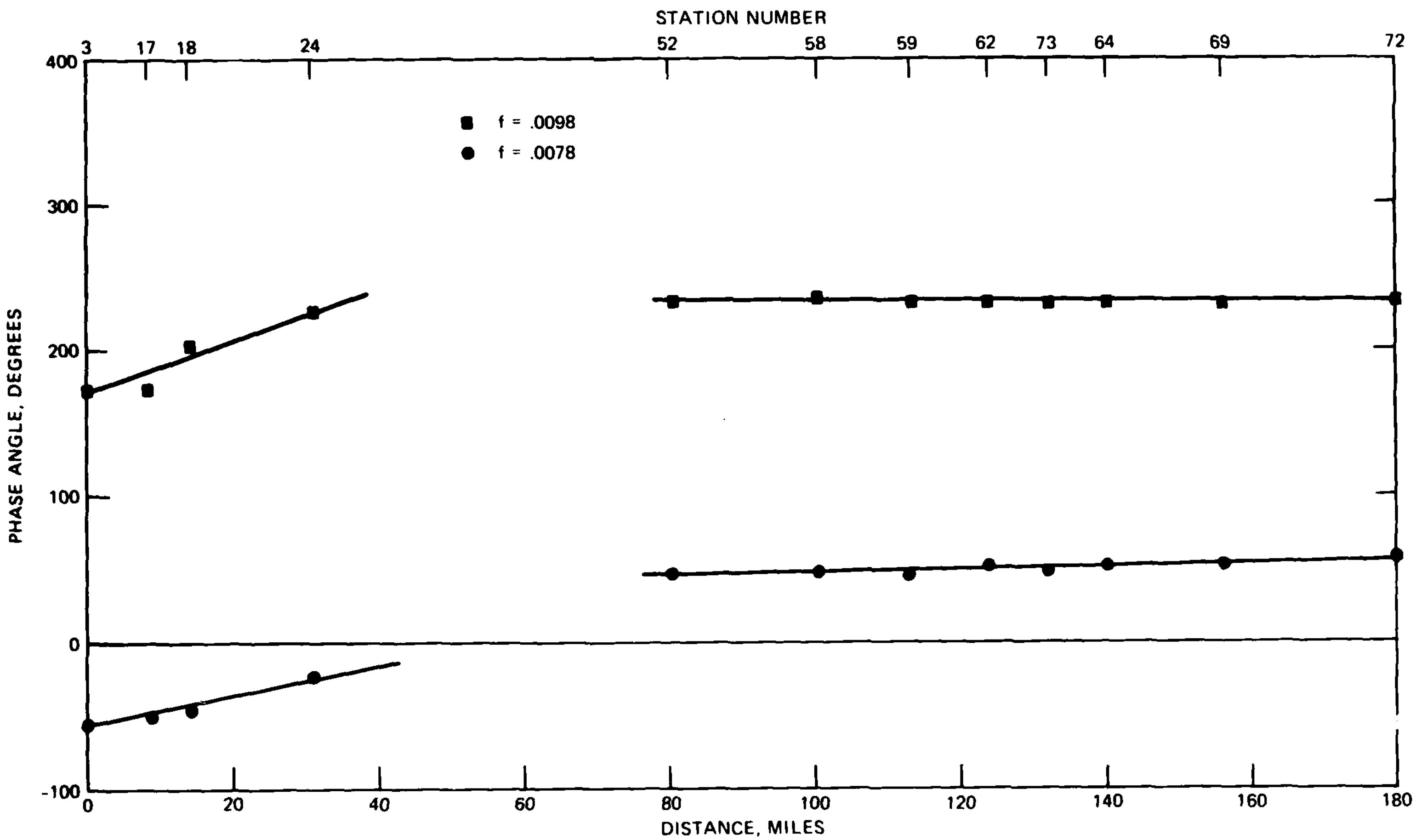



Figure 18. Phase angle at low frequency

interval of 0 to $\pi$ for an even function such that: $f(t) = f(-t)$ for all values of time (t). The coefficients were derived as follows:

$$f(t) = \sum_{n=0}^{N} a_n \cos(nt) \tag{2}$$

Therefore

$$a_o = \frac{1}{\pi} \int_o^{\pi} f(t)\, dt \tag{3}$$

$$a_n = \frac{2}{\pi} \int_o^{\pi} f(t) \cos(nt)\, dt \tag{4}$$

where

$f(t)$ = weighting function such that $f(t) = 1.0$ for period $\leq 36$ hr and 0.0 for period $> 36$ hr

$N$ = number of coefficients, chosen as 24

$n$ = coefficient number

$a_n$ = Fourier expansion coefficients

The frequency domain separation point is defined as

$$\omega_s = \frac{2\pi t_s}{T} \tag{5}$$

where

$t_s$ = sampling interval of data

$T$ = desired separation period

The Lanczos correction factor ($\sigma$) (Lanczos 1961) was used to smooth the filter and produce a smoother frequency separation. These coefficients are

$$\sigma_n = \frac{\sin (n\pi/N)}{n\pi/N} \tag{6}$$

The final form, as applied to some water-level time series $h(t)$ is

$$\overline{h(t)} = a_o h(t) + \frac{1}{2} \sum_{n=1}^{N} a_n \sigma_n \left[h(t - nt_s) + h(t + nt_s)\right] \tag{7}$$

where $\overline{h(t)}$ equals low-frequency portion of the water-level time series. Effectiveness of this filter, both with and without the Lanczos correction factor, is shown in a plot of the frequency response function in Figure 19. Isolation of the source of the low-frequency energy was accomplished as follows. For analysis purpose, three time periods were selected that contained the most complete main bay area coverage of tidal height data; wind data were also available for the same time periods. Time periods with associated tide stations and wind stations are listed in Table 2.

44. The filter was applied to both tidal height data and wind data. Effectiveness of the filter in separating the short- and long-period portion of data is shown in Figures 20 and 21. Figure 20 shows raw tidal data from sta 59 and Figure 21 shows the high- and low-frequency components of the raw data after application of the filter. As shown in this example, the separation achieved is very effective.

45. Wind data used were in the form of wind speed in nautical miles per hour (knots) and direction in degrees. Wind vectors were reduced to north-south components (since the direction parallel to the longitudinal axis was of primary interest) and then filtered to obtain the low-frequency portion of the record. This resulting long-period (low frequency) component of the wind field was plotted against time. Southerly winds were plotted positive since winds from the south force additional water into the bay, thereby raising water levels in the upper bay; conversely, northerly wind components were plotted negative.

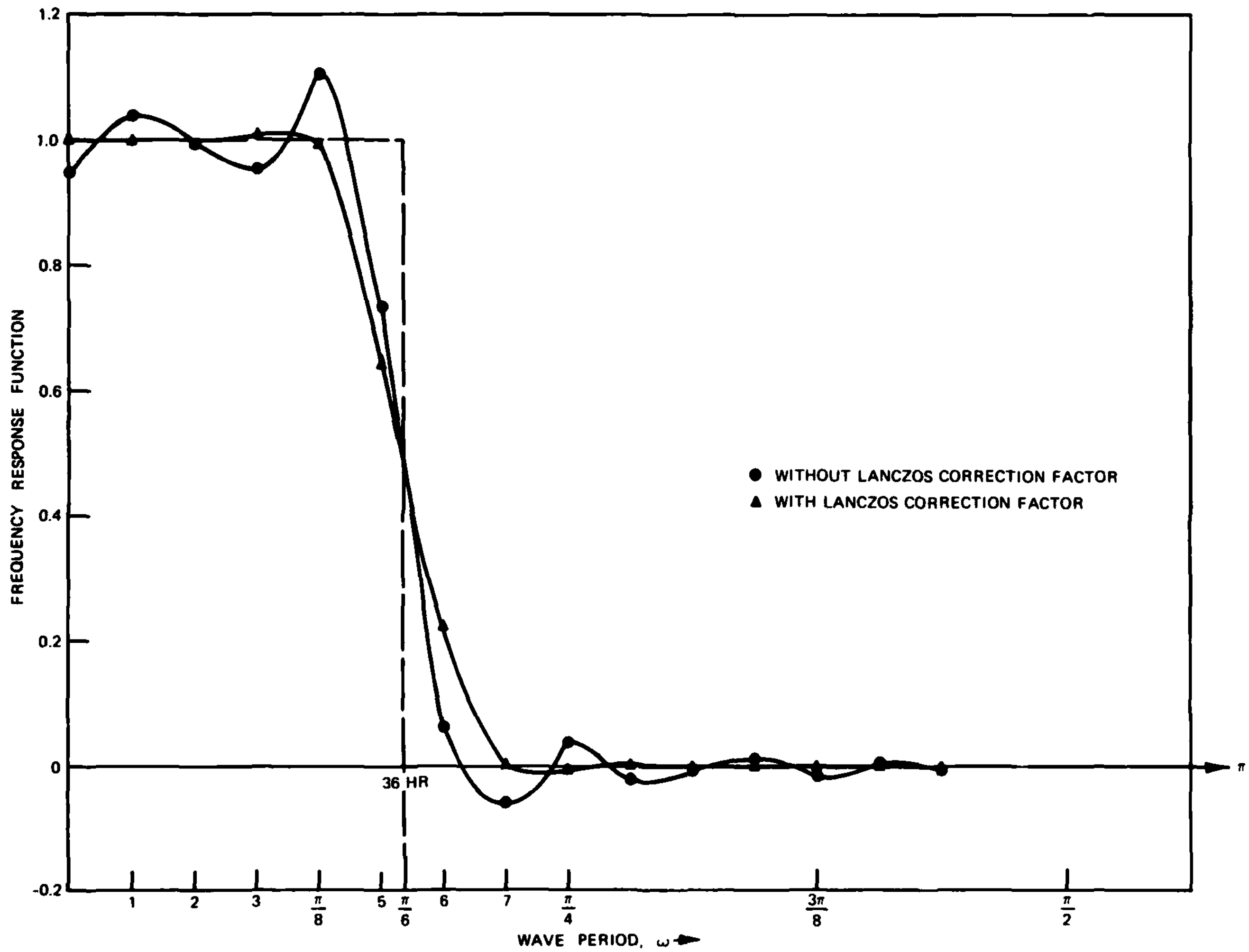



Figure 19. Digital filter frequency response function

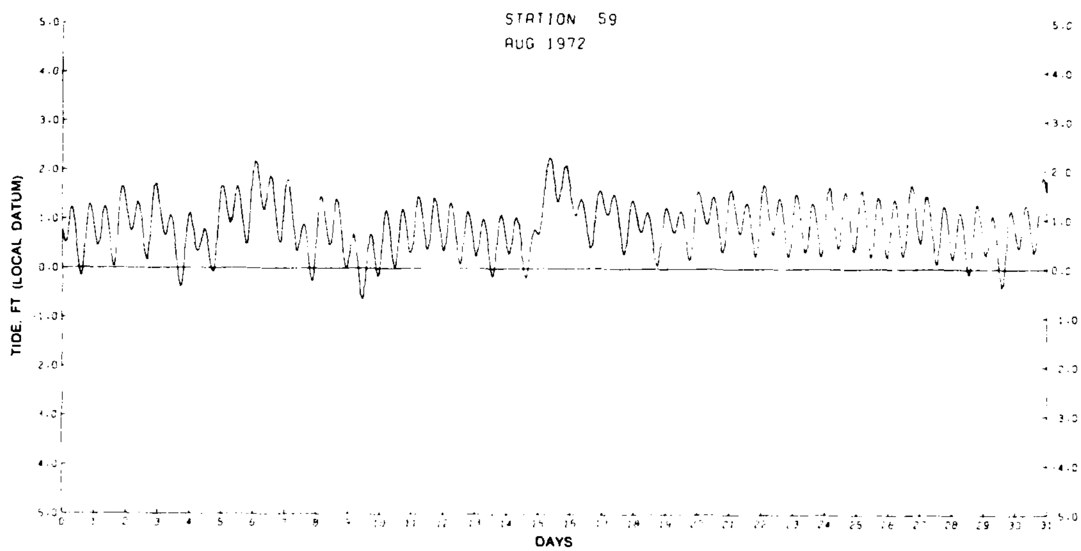



**Figure 20. Raw tidal data**

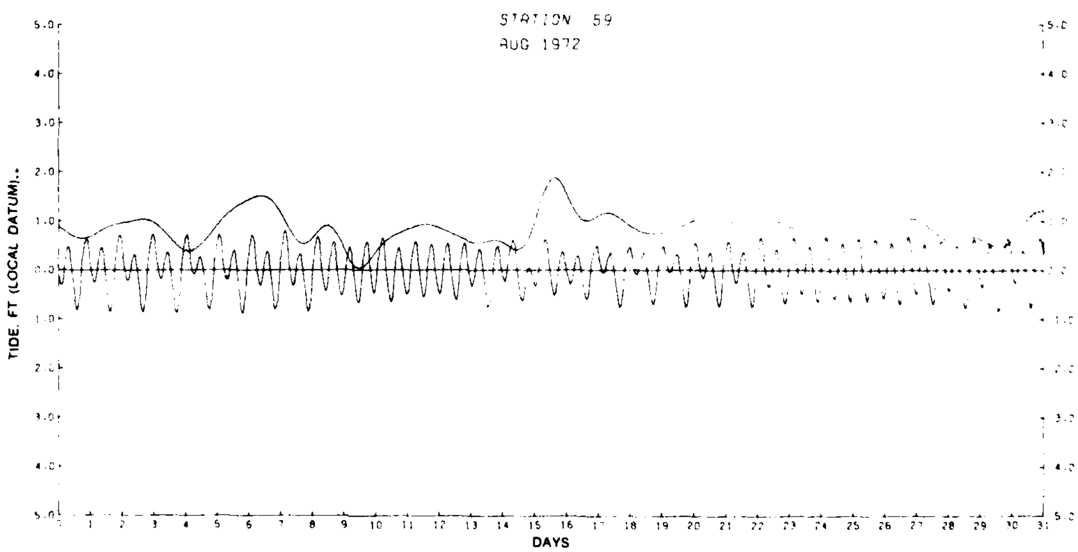



**Figure 21. High- and low-frequency portions of raw tidal data**

Figures 22a, b, and c show these components for each weather station listed in Table 2 for each time period. Similarities shown in each of these plots demonstrate the general trend that the major wind field (both magnitude and duration) acting on the bay system behaves approximately the same over the entire bay. Although station-to-station wind magnitude comparisons cannot be made due to variations in anemometer height and exposure, wind-field trends at any wind station are generally indicative of the overall wind field acting on the bay.

46. To correlate wind fields with the long-period fluctuations in tidal height, the filtered tidal height data were plotted versus time in a manner similar to those of the wind fields. Figure 23 shows one such plot for three concurrent tidal height series.

47. These filtered (long-period) tidal height series were differentiated with respect to time (dh/dt) by computing the change in filtered tide height per unit time based on the time interval between adjacent data points. These resulting series were smoothed by means of a simple three-point sliding filter and plotted versus time. Figures 24a, b, and c show this relationship for several of the tide stations for the three time periods studied. Relationships of dh/dt were used rather than actual long-period tidal heights since they reflect the immediate water-surface response, indicate the precise length of time of either increase or decrease of water level, and remove the mean tide level from each data series.

48. Visual comparisons of wind fields and water levels were made by simply superimposing all the plots similar to Figures 22a, b, and c on all the plots similar to Figures 24a, b, and c. Wind-speed components were scaled by a factor of one-tenth to yield plots of visually compatible magnitude. Figures 25a, b, and c show typical comparisons for a representative wind station and a representative tide station for each of the time periods used. A great amount of similarity in both phasing and shape of these two parameters is shown.

49. A relationship of increasing long-period tidal response with distance from the mouth of the bay can readily be seen in Figures 24a, b, and c. In view of this relationship and the similarities shown in

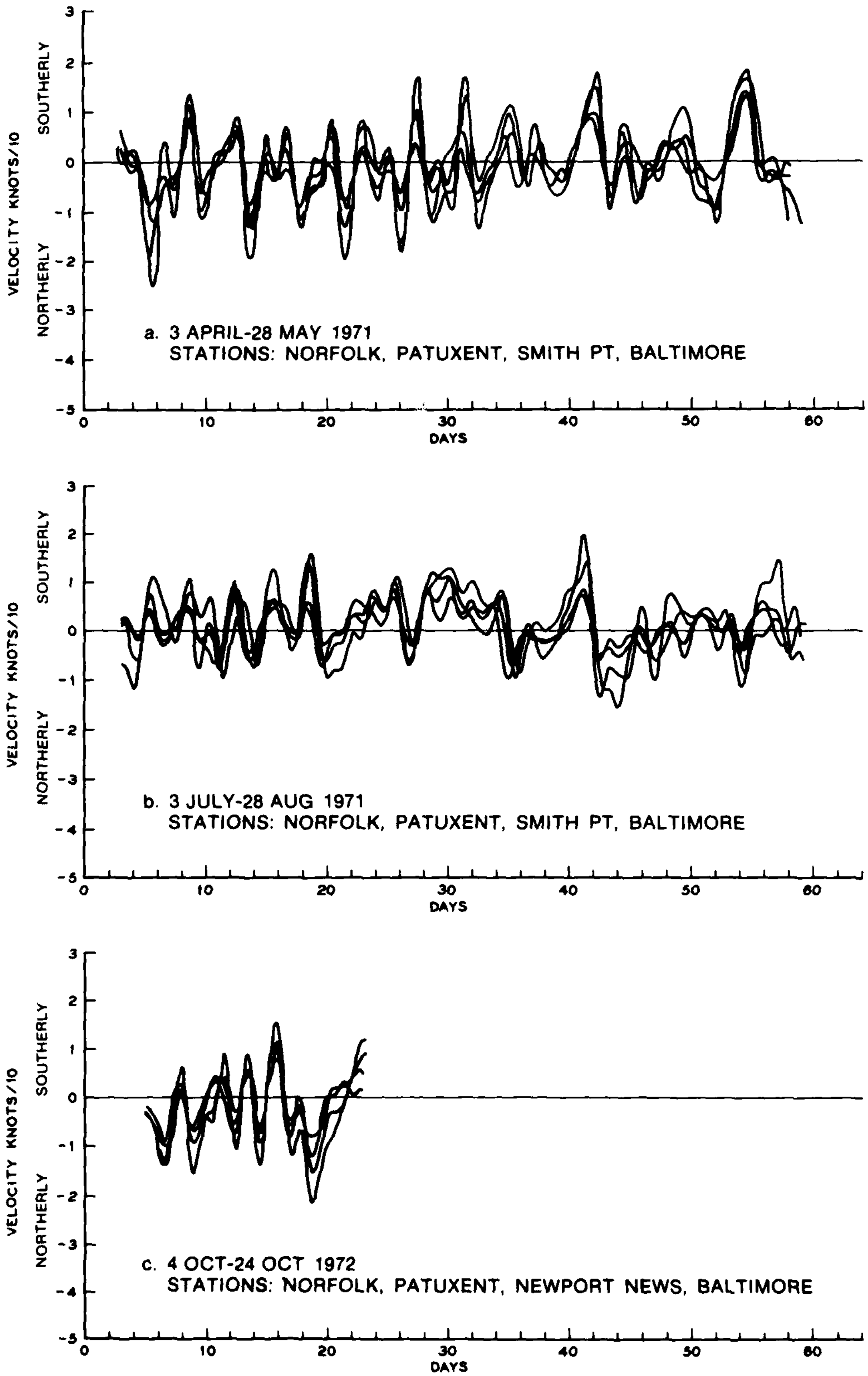



Figure 22. Long-period north-south wind vectors

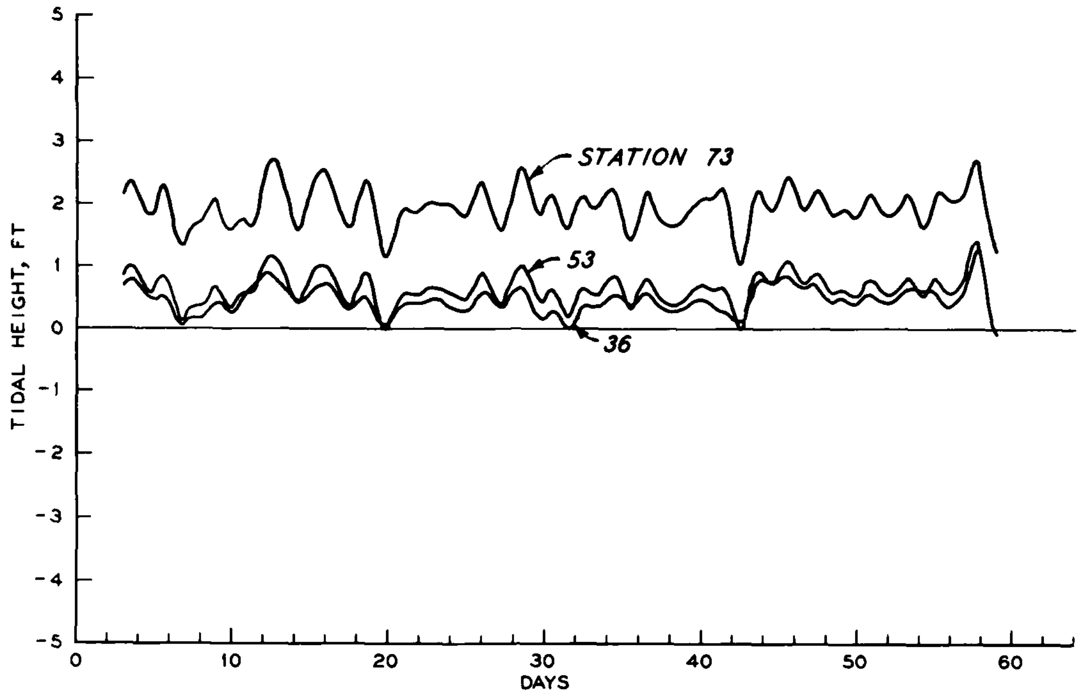
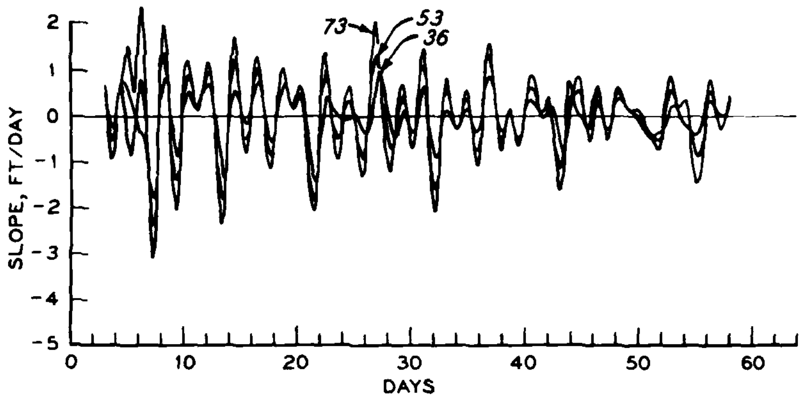
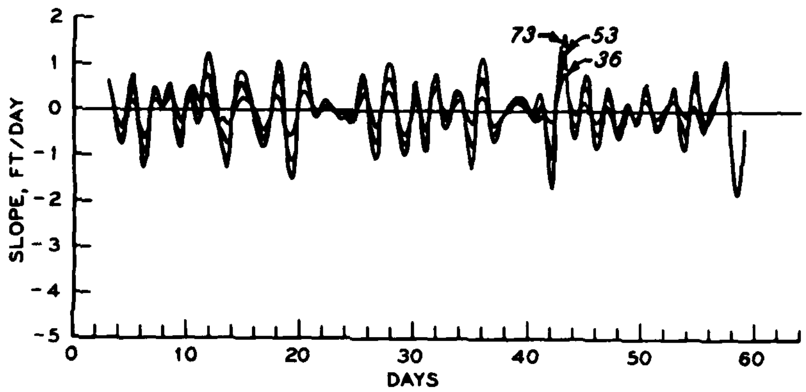



Figure 23. Long-period water surface 3 Jul-28 Aug 1971

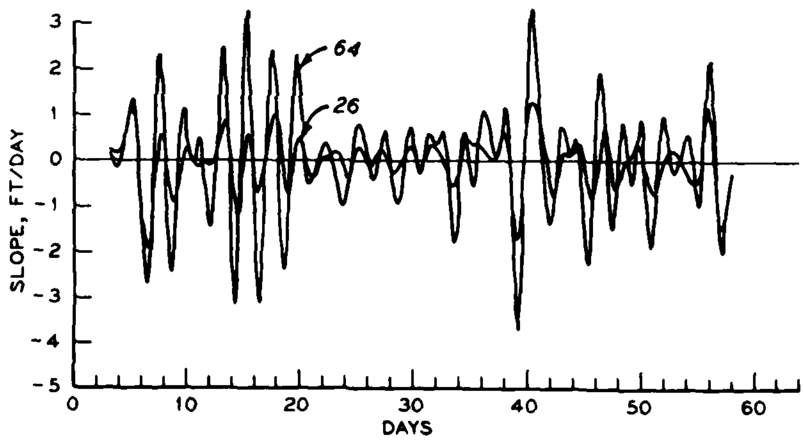
Figures 25a, b, and c, comparisons were made with the filtered north-south component of the wind field and the instantaneous axial long-period water-surface slope of the bay. This slope was calculated by filtering raw tidal height data from four stations in the bay (sta 18, 36, 53, and 73) to obtain the long-period component of the series. The arithmetic mean for each of the resulting series was removed from each respective set of data resulting in four instantaneous long-term tidal series with a zero mean. For each time increment, the four values were input to a least-squares type linear fit routine giving an overall slope of the water surface in the bay and an intercept value. The slope value, in feet per 100 miles, was plotted with the corresponding filtered north-south wind component. Figure 26a shows this slope plotted with an average long-period wind-field vector calculated by averaging data from four wind stations for April-May 1971. Figure 26b shows the slope plotted against wind data from the Patuxent Naval Air Station for the July-August 1971 period. Resulting plots indicate wind stress on the bay to be the




a. 3 Apr-28 May 1971, tide sta 36, 53, 73

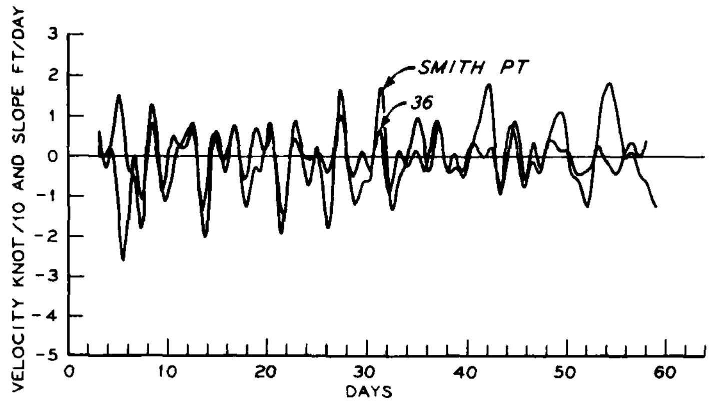



b. 3 Jul-28 Aug 1971, tide sta 36, 53, 73

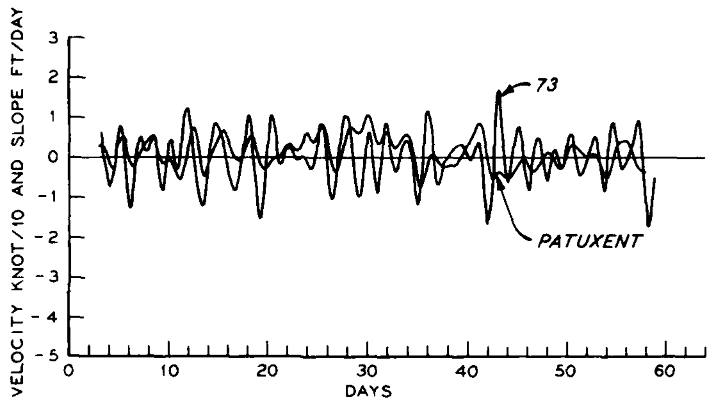



c. 3 Oct-27 Nov 1972, tide sta 26, 64

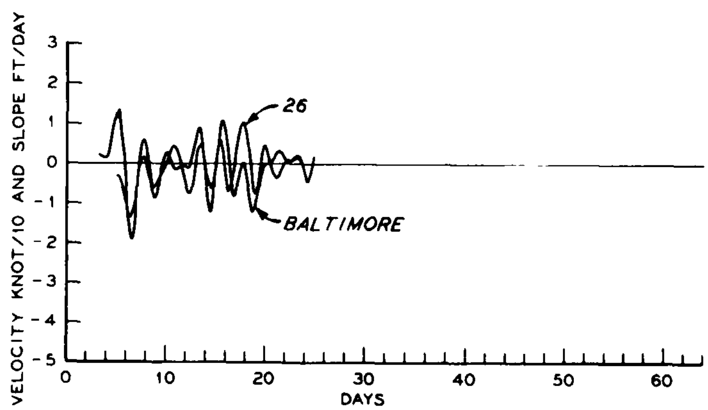
Figure 24. Time slope of long-period water surface (dh/dt)




a. 3 Apr-28 May 1971, wind sta Smith Pt, tide 36

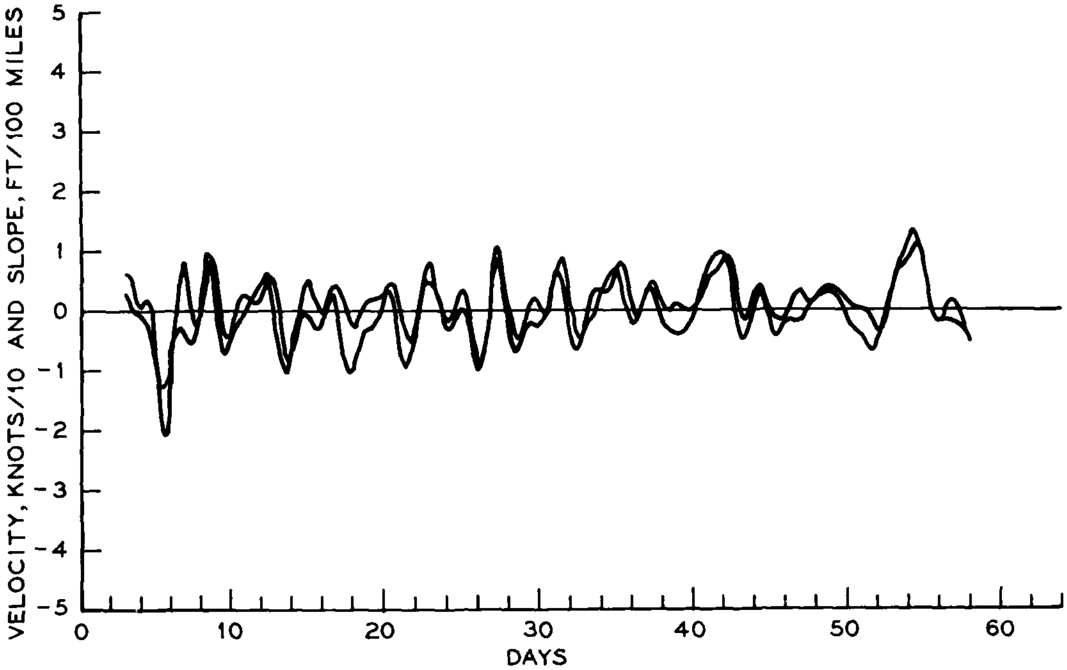



b. 3 Jul-28 Aug 1971, wind sta Patuxent, tide 73

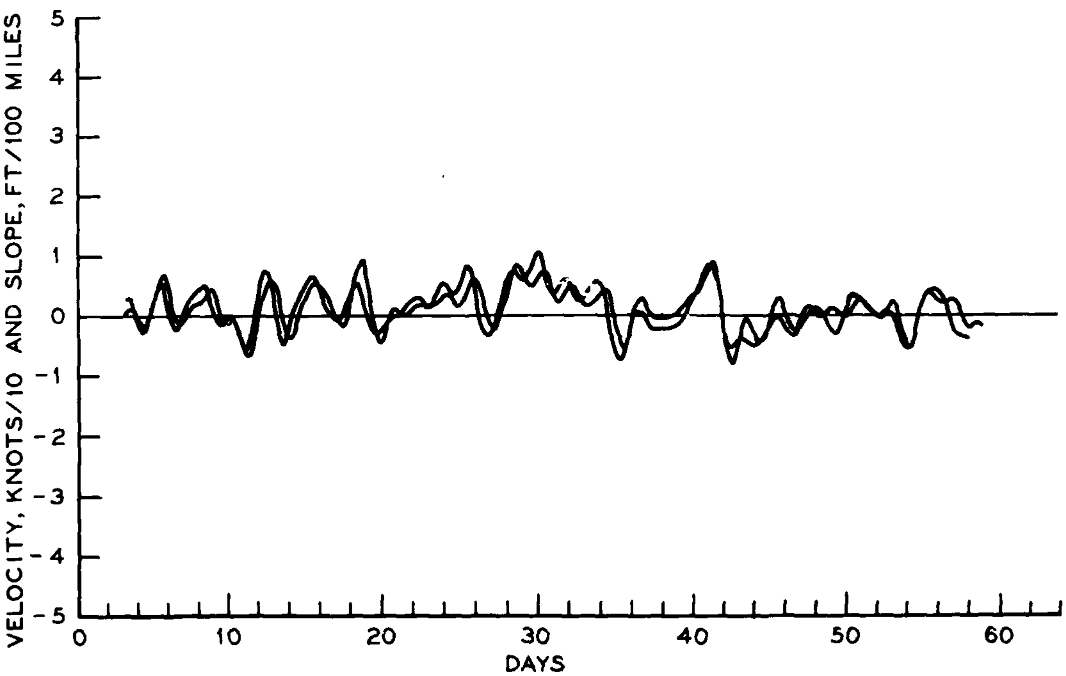



c. 3 Oct-24 Oct 1972, wind sta Baltimore, tide 26

Figure 25. Long-period wind velocity and long-period water-surface slope (dh/dt)




a. 3 Apr-28 May 1971, average wind field




b. 3 Jul-28 Aug 1971, Patuxent wind station

Figure 26. Long-period wind velocity and long-period water-surface slope of the bay

primary source of the nonastronomical long-period waves seen in the data.

50. Quantitative analysis of the wind stress on the bay was not pursued since this effect could not be duplicated by the model. The important fact was that the source of the low-frequency energy had been identified and that these effects could be removed from the prototype data where possible or taken into consideration when necessary.

## PART V: MODEL VERIFICATION

51. Accurate reproduction of hydraulic and salinity phenomena is essential before any model can be used as a predictive tool for the evaluation of proposed changes to an estuarine system. Conventional methods of physical model calibration and verification could not be followed at the Chesapeake Bay model because of the highly nonsynoptic nature of the prototype data and the existence of a substantial amount of low-frequency, nonastronomical energy present in the data. An alternate approach of verification to primary astronomical tidal constituents was employed. This type of approach has been shown to be effective in verifying tide heights for tidal inlet models (Whalin, Perry, and Durham 1976); therefore, this procedure was extended to include both tidal height and tidal velocity verification.

52. Two separate modes of operation were followed at the Chesapeake Bay model. Verification for tidal heights and tidal velocities entailed a steady-state type of boundary control operation using a repetitive $M_2$ constituent source tide and a constant long-term (annual) average freshwater inflow condition. Verification for salinities employed a repetitive 28-day, 12-constituent, tidal cycle with prototype inflow hydrographs reproduced in 2-week average time-steps.

53. The following sections contain the pertinent details of these procedures. Summary type comparisons of model versus prototype data are included in the main text of this report. A representative number of model-prototype data comparisons are included in the appendices. Because of the vast amount of raw prototype data and model-prototype comparisons used for model verification, all data not included in the appendices are on file at WES.

### Tidal Height Verification

54. The objective of tidal height verification is to obtain an accurate reproduction of tidal amplitudes, phase angles, and mean tide levels. As shown in Table 3, based on linear wave theory (Ippen 1966)

and harmonic analysis, the $M_2$ tidal constituent was found to account for over 90 percent of the total (potential plus kinetic) astronomical energy of the bay system. Therefore, the $M_2$ constituent was chosen for tidal verification.

55. Reconstruction of the $M_2$ tide was based on the relationship

$$h(t) = A_o + a \cos\left(\frac{2\pi\omega t}{360} - \frac{2\pi\varepsilon}{360}\right) \quad (8)$$

where

$h(t)$ = $M_2$ tide height at time $t$, ft

$t$ = time, hr

$A_o$ = mean height above reference datum (Mean Tide Level - Sea Level Datum), ft

$a$ = $M_2$ amplitude, ft

$\omega$ = $M_2$ constituent angular velocity, deg/hr

$\varepsilon$ = phase angle (epoch) in degrees measured from equilibrium tide passing Greenwich at 0 hour GMT

One-year harmonic analyses were performed on 49 tidal stations with 29-day analyses performed on an additional 19 stations for seasonal averages. These results provided the $M_2$ tidal amplitude and epoch values used in Equation 8 for use in verification. Adjusted mean tide elevations for the prototype were computed by subtracting Sea Level Datum (SLD), 1929 National Geodetic Vertical Datum (NGVD) supplied by NOAA, from the mean tide level (MTL - SLD). Table 4 provides the $M_2$ component amplitudes and epochs obtained from the harmonic analyses and the MTL - SLD values as provided by NOAA.

56. During the beginning phases of calibration the model was filled with fresh water and a tide with an $M_2$ frequency was repeatedly generated at the ocean tide generator. Several main bay stations were examined as a possible tide control station since data for the ocean station (sta 1) were not available for the prototype collection period. Sta 3, Old Point Comfort, at the entrance to the James River, was found to be the most feasible control station. Adjustments to the ocean tide generator were made until an accurate reproduction of the $M_2$ tide at

sta 3 was accomplished. At this time, many iterations of roughness strip adjustments were performed in a longitudinal progression up the bay and rivers until the tidal propagation (time of arrival and amplitude) at the model tide stations approximated that of the prototype.

57. During the final phases of calibration and verification, additional boundary conditions were maintained. An $M_2$ amplitude and epoch-based tide were produced at both the primary and secondary tide generators. The ocean tide was then adjusted to produce the desired tide at sta 3. Datum at Reedy Point (the secondary tide generator) was set to yield a zero net flow through the C&D Canal. A constant ocean source salinity was maintained at 31 ppt and a salinity of 3 to 5 ppt, corresponding to the average salinity of Reedy Point in Delaware Bay, was maintained at the secondary tide generator. The long-term average freshwater discharge was constantly introduced through the 21 inflow points. These values, calculated and provided by NAB, are shown in Table 5.

58. Manual point gage measurements were taken at each prototype hour (36 sec model) at each of the tide stations during a test to obtain a 24-hr series of tidal elevations. This series was input to an $M_2$ constituent-only, harmonic analysis to yield a model $M_2$ amplitude, phase angle, and mean tide elevation for comparison with adjusted prototype values. In general, excellent agreement between model and prototype amplitudes and phase angle was achieved, indicating correct model adjustment; however, discrepancies with respect to mean tide elevations were found. Much effort was expended in an attempt to resolve this problem since it was inconceivable that the model could reproduce tidal amplitudes and phase angles, yet have mean tide elevation errors as great as those indicated in the model tests.

59. Figure 27 illustrates one of the preliminary mean tide elevation versus distance up the bay plots. As shown, the difference between model and prototype mean tide elevation increases with distance from the mouth of the bay indicating a prototype mean tide level slope up the axis of the bay approximately twice that observed in the model tests. Results of a preliminary test with similar boundary conditions, with the exception that the Reedy Point datum was set to produce a net easterly flow of

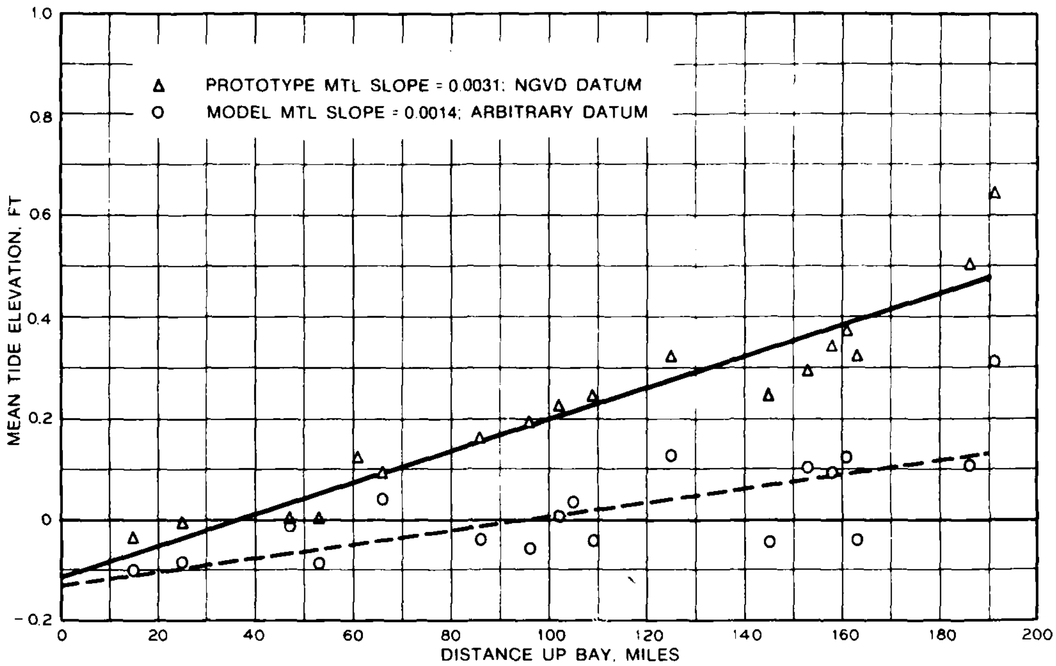



Figure 27. Mean tide level slopes, 28 Mar 1978 verification test

4300 cfs (Boyd et al. 1973), showed approximately the same results (Figure 28). Model values for both tests were based on a pooled model water level to establish zero datums for all gages. This datum is difficult to refute as an equipotential surface and, therefore, a valid model datum. Additional analyses and attempts at model adjustments proved unsuccessful. At this time, the prototype values for the NGVD were questioned; however, personnel from NOS and USGS were unable to supply a satisfactory solution.

60. The solution to the problem appeared to be a systematic error in prototype geodetic leveling. Similar conclusions have been reported by Sturges (1967) based on earlier work by Edge (1959). These studies show a systematic error in leveling due to an apparent optical effect of sunlight versus diffuse light on the reading of leveling rods along a north-south axis. Sturges' results were based on steric sea leveling data. The magnitude of the error was reported to be 3.5 cm (1.37 in.) per degree of latitude. Since this value appeared to be consistent with the discrepancy found in the datum of Chesapeake Bay, it was applied to

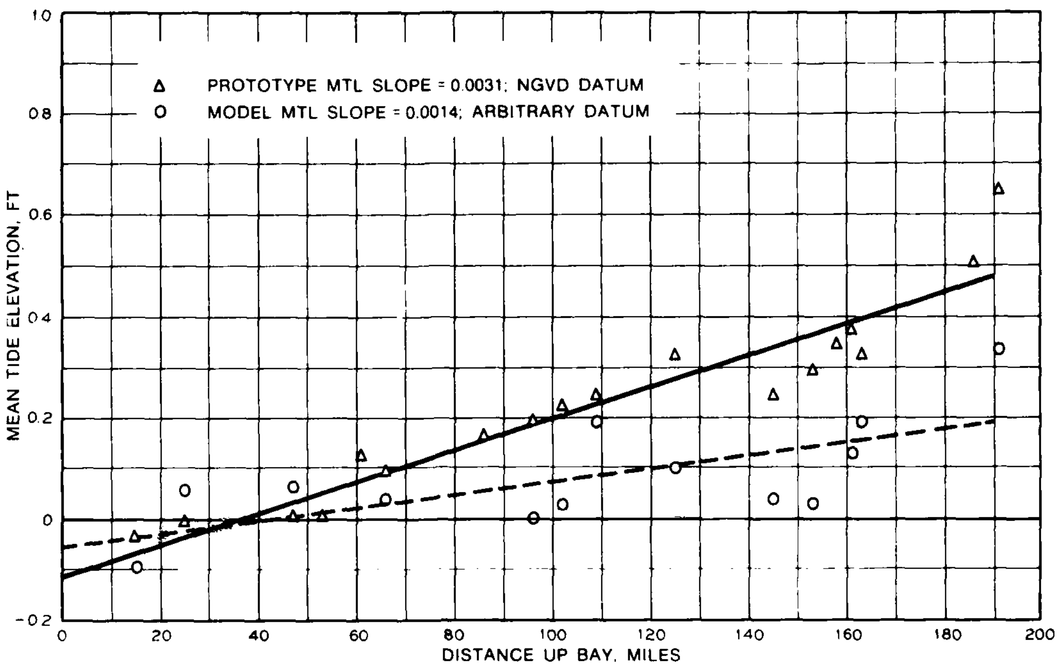



Figure 28. Mean tide level slopes, 13 Jun 1977 verification test

the NGVD values used in the prototype tidal height analyses.

61. Prototype data used in Figures 27 and 28 were replotted against model data; however, this time 3.5 cm (1.37 in.) was subtracted from the adjusted mean tide elevation for the prototype for each station for each degree of latitude measured north from sta 3 (Figures 29 and 30). Since the model had achieved excellent agreement in tidal height amplitudes and phase angles, this adjustment to the prototype datum completed the final comparison necessary for accurate tidal verification of the Chesapeake Bay model. Over the entire length of the bay (sta 3 to sta 72), this adjustment varied from 0.00 to 0.29 ft.

62. Table 6 provides the final verification values for model and prototype tidal amplitudes, phase angles (time of arrival), and tidal planes. Individual model to prototype comparison plots for each station are included in Appendix B in Plates B1-B32. Specific details of model control during the verification test are provided in Acres American Test 20 Boundary Control Report (Bridgeman 1978b). The datum plane on each plate is based on the pooled model.

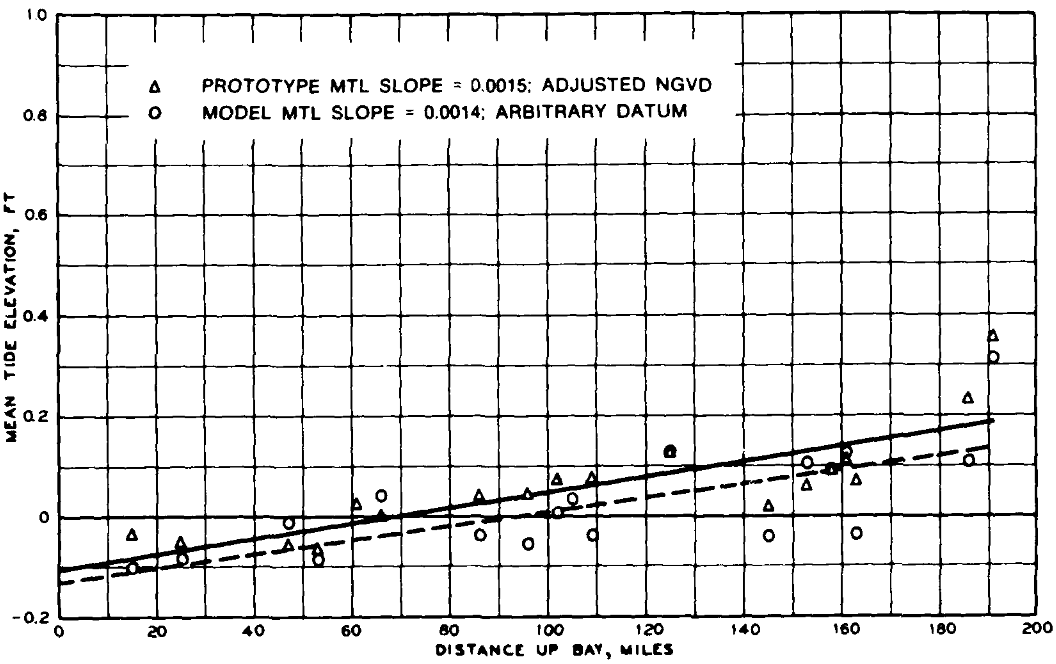



Figure 29. Mean tide level slopes with adjusted prototype NGVD, 28 Mar 1978 verification test

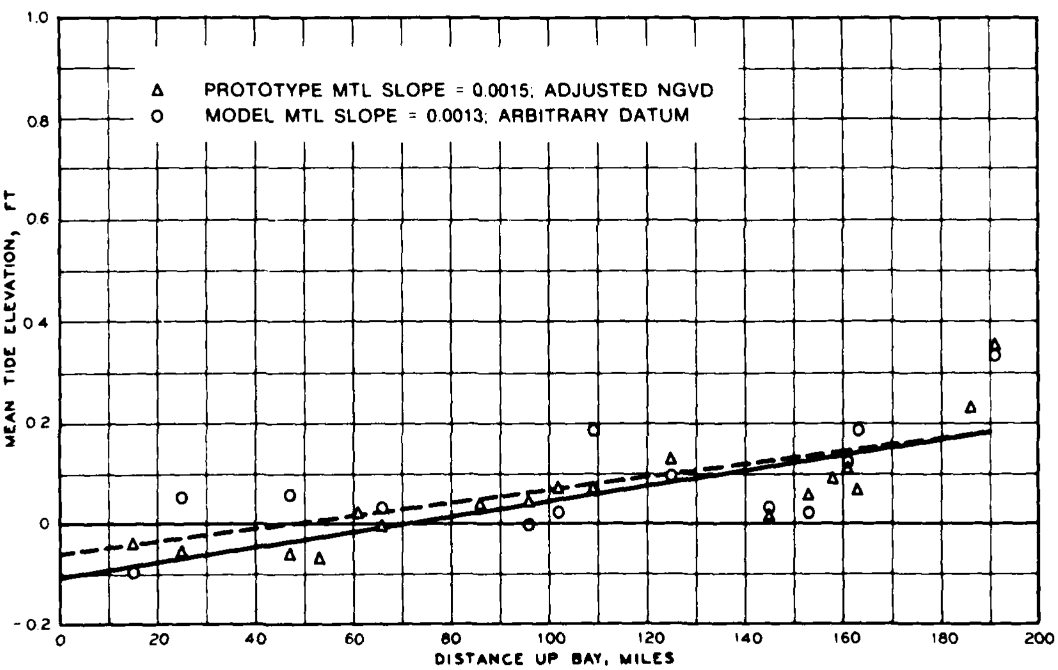



Figure 30. Mean tide level slopes with adjusted prototype NGVD, 13 Jun 1977 verification test

## Velocity Verification

63. The objective of velocity verification is to achieve an accurate reproduction of velocity amplitudes, phase angles, and mean velocity values (an indicator of predominance of flow) in the model. The procedure followed for verification was first to develop prototype $M_2$ data for model-prototype comparisons and then to further adjust the roughness distributions so that acceptable reproduction of $M_2$ velocity amplitudes, phase angles, and mean values were produced at all velocity stations. This was accomplished by making lateral adjustments in the roughness distribution of the model, while statistically maintaining the same percentage distribution in the areas of the model between tide station locations. This was necessary in order to maintain proper tidal height and propagation agreement.

64. Isolation of an $M_2$ velocity component from the raw prototype data presented a much greater problem than the isolation of the corresponding tidal height component. The difficulty was in eliminating the wind contamination effect so that an $M_2$ velocity constituent could be extracted from the nonsynoptic current measurement series, which were of an average of 5-day duration. The major problem was posed by the short length of data series containing superimposed wind contamination with a period of the same order as the length of data. The following technique was used to separate the $M_2$ component from the velocity record which contained both the diurnal and primary semidiurnal constituents ($M_2$, $N_2$, and $S_2$) and to determine the effects of the wind stress on the velocity data series.

65. A one constituent ($M_2$) harmonic analysis was applied to each of the 691 usable raw velocity data series. This analysis provided an acceptable $M_2$ phase angle; however, the amplitudes obtained in this manner also reflect the amplitudes of the $N_2$ and $S_2$ semidiurnal constituents. This is unavoidable since data series of lengths equal to synodic periods of two constituents to be separated are required for complete separation. The data series lengths necessary for separation of the three major semidiurnal constituents are:

$M_2 - S_2$ 14.765 days

$M_2 - N_2$ 27.555 days

$N_2 - S_2$ 9.614 days

Since the velocity data series averaged 5 days in length, a ratio technique was used for separation that would reflect the interaction of the constituents over the specific 5-day period in which data were taken. Wind effects were neglected at this point.

66. A harmonic analysis, using 12 major diurnal and semidiurnal constituents, was applied to 2 months of tidal elevation data from a centrally located main bay tide station (sta 53) beginning on 1 June 1971. The resulting individual constituent amplitudes and phase angles were used to synthesize a tidal record at sta 53 for approximately 3-1/2 years covering the period in which prototype data were taken. This was based on the relationship

$$H(t) = \sum_{n=1}^{12} a(n) \cos \left[ \frac{2\pi t \omega(n)}{360} - \frac{2\pi \varepsilon(n)}{360} \right] \quad (9)$$

where

$H(t)$ = synthesized tidal record at time $t$

$t$ = time

$a(n)$ = constituent amplitude, ft

$\omega(n)$ = constituent angular velocity, deg/hr

$\varepsilon(n)$ = constituent phase angle, deg, measured from 1 June 1971

67. A 5-day, one constituent ($M_2$) harmonic analysis was then used on the synthesized series of data beginning on 1 June 1971, and leapfrogged every 12 hr (24 points at a time increment of 0.5 hr). For example, at 0.5-hr intervals, there are 240 data points in 5 days and harmonic analyses were run using points 1-240, 25-264, 49-288, etc., until the entire period was spanned. This resulted in an $M_2$ tidal amplitude and phase angle for each 5-day data series beginning at time zero and then at each successive 12-hr time increment. This resulting

amplitude included the amplitudes of the additional harmonic constituents in the same way that the results of the one constituent harmonic analysis of the raw prototype velocity data included the additional constituents.

68. Since the bay has been shown to be basically linear with respect to the propagation of shallow-water waves (PART IV), the assumptions of linear wave theory were used to show a proportionality between the tidal height amplitudes and the horizontal tidal velocity amplitudes. This can be shown using the following definitions:

$$\phi = \frac{\sigma a}{k} \frac{\cosh k(h + z)}{\sinh kh} \sin (kx - \sigma t) \tag{10}$$

$$\eta = a \cos (kx - \sigma t) \tag{11}$$

$$u = \frac{\partial \phi}{\partial x} = \sigma a \frac{\cosh k(h + z)}{\sinh kh} \cos (kx - \sigma t) \tag{12}$$

where

$\phi$ = velocity potential

$\sigma$ = frequency = $2\pi/T$

T = period, hr

a = amplitude, ft

k = wave number = $2\pi/L$

L = wavelength, ft

h = mean depth, ft

$\eta$ = wave height above msl

u = horizontal velocity

z = vertical axis

Based on these relationships, the following proportionality was used to determine the long-term velocity amplitudes from the corresponding long-term tidal height amplitudes and the velocity and tidal height amplitudes associated with the short 5-day records.

$$\frac{H}{h} = \frac{V}{u} \tag{13}$$

where

$H$ = long-term $M_2$ component tidal amplitude

$h$ = short-term $M_2$ tidal amplitude, derived from one constituent harmonic analysis of 5-day segment of the 3-1/2-year synthesized tide

$V$ = long-term $M_2$ component horizontal velocity amplitude (to be used in verification)

$u$ = short-term $M_2$ component horizontal velocity amplitude derived from the one constituent harmonic analysis of the short 5-day raw prototype data series

The above-described relationship is valid for linear waves if the assumption is made that the wave numbers $k$ and the frequency $\sigma$ of the long- and short-term data series are equal. This can be seen by setting the ratio of wave heights for long- and short-term components equal to the ratio of velocities for long- and short-term components and canceling the cos, cosh, and sinh terms containing $k$ and $\sigma$. This is a reasonable assumption. In this procedure, both $h$ and $u$ are obtained from comparable short data series by application of the $M_2$ only harmonic analysis. Velocity $M_2$ constituent amplitudes were then computed for each velocity data series by applying the adjustment factor calculated for each specific time period in which prototype data were collected. This factor was applied as follows:

$$V = \frac{H}{h} u \qquad (14)$$

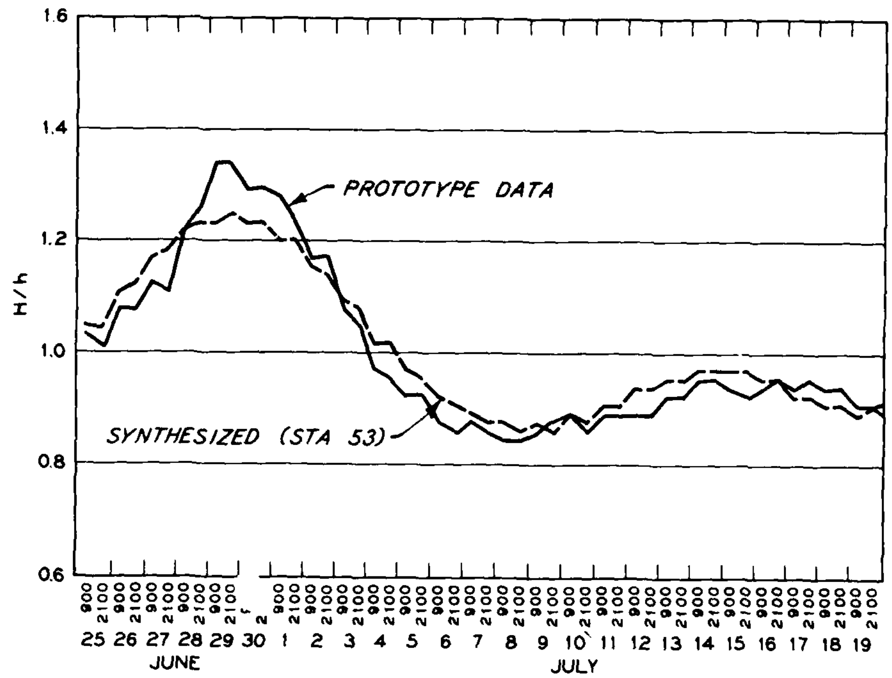
69. The procedure above yields an effective $M_2$ velocity amplitude that represents the interrelationships of the various astronomical constituents for the specific time period in which prototype velocity data were taken; however, it will not account for the effects of wind stress. For this reason, a similar procedure was performed using actual prototype tidal height data series instead of the 3-1/2-year synthesized tidal series. This was done not only to verify the procedure but also to qualitatively determine the effects of the wind fields. These effects were shown by comparing the resulting adjustment factors from the two procedures.

70. Results of the adjustment factor comparisons are demonstrated

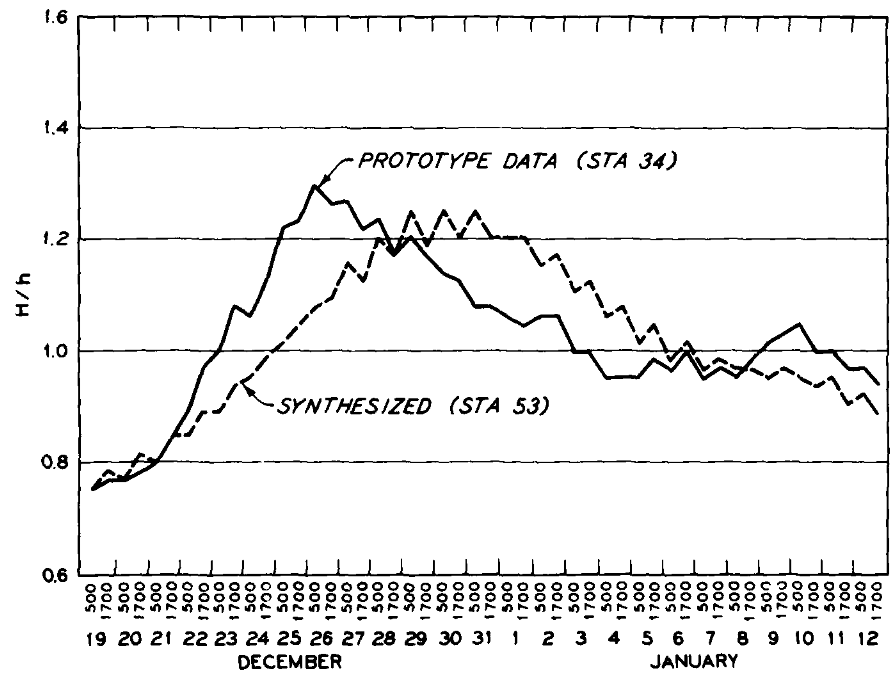
in Figure 31. The upper diagram illustrates the variation of the multiplier H/h (by which u must be multiplied to obtain V for a 5-day period beginning on the date and time given in 12-hr increments on the abscissa) with time at sta 53. The curve designated as "Synthesized" was obtained as outlined above; the curve marked as "Prototype Data" was obtained using the actual prototype tidal height series instead of the 3-1/2-year synthesized tidal series at the station. The comparison indicates the general validity of the procedure.

71. The lower diagram in Figure 31 indicates how the H/h multiplier derived for the synthesized tide at sta 53 compared with the multiplier obtained from analysis of the raw prototype data at sta 34 for comparable times. The diagram provides an indirect indication that different sections of the bay respond in a comparable way to wind fields over the bay. Similar results were obtained for other locations in the bay, with good agreement between the multipliers based on the sta 53 synthesized tide and prototype tide data at the respective stations. Therefore, it was concluded that the H/h multiplier based on the synthesized tide at sta 53 could be used to approximate the $M_2$ velocity amplitude at the various stations and times corresponding to velocity data collection periods. Although the adjustment factor based on the synthesized tide was used to determine the $M_2$ velocity, the factor computed from actual tidal records was compared with the synthesized factor for each time period in which prototype data were collected. In virtually all cases, agreement was very good (less than 10 percent deviation). For this reason, and the fact that many velocity stations were sampled at times when adjacent tidal height data were not available, the synthesized factors were used.

72. Two separate velocity verification tests were performed. Main bay velocity stations were sampled during the final tidal verification test (Test 20). River velocity stations were sampled during a separate test, Test 22, conducted with similar boundary conditions except that an ocean source salinity of 30 ppt was maintained instead of 31 ppt as maintained during Test 20. The source salinity was reduced to produce values more reflective of the prototype. Specific details of boundary




a. Time, day-hour-1971




b. Time, day-hour-1973

Figure 31. Prototype H/h values versus H/h values derived from synthesized tide at sta 53

control during Tests 20 and 22 may be found in Acres American Test 20 Boundary Control Report (Bridgeman 1978b) and Test 22 Boundary Control Report (Stoll and Hayden 1978).

73. The amplitudes, phases, and mean values (averages) of model and prototype velocities at all velocity measurement points for Tests 20 and 22 are shown in Tables 7 and 8. Two additional summary comparisons along with model-prototype plots for the middepth location for each primary velocity station are included in Appendix C. The first set of comparisons consists of graphs of the depth profile of model and prototype velocity amplitudes (fps) and associated phase angles (degrees). These plots, shown in Plates C1-C8, are summarizations of the main bay velocity data shown in Table 7 of the text. The second comparisons, also shown only for the main bay ranges, are summaries of the difference in arrival times and amplitudes between the model and the prototype. These are shown in Plates C9 and C10. Each graph in Plate C9 shows, for the individual velocity station and depth (station/depth), how early or late the model value was in comparison with the prototype. For example, in Plate C9 for Range CB00, sta 2 data at a depth of 20 ft had an arrival time of between 1/2 hr and 1 hr earlier than the prototype. Each graph in Plate C10 shows, for the individual velocity station and depth (station/depth), the deviation in velocity amplitude (feet per second) of the model from the prototype. Plates C11-C82 show model to prototype middepth velocity tidal cycle comparisons. The A(0) value shown in these plots is essentially that of the average or mean value. All remaining plots and data not included in this report are on file at WES.

## Salinity Verification

74. The objective of salinity verification is to obtain an accurate reproduction of the prototype salinity regime. The more conventional verification of direct model-prototype comparison was necessary due to the limitations imposed by the prototype data. This was accomplished by a model comparison to two different types of prototype data. The first was a comparison of the same slack salinity values which

usually corresponded to slack after ebb. These data were taken along the longitudinal axes of the bay and major tributaries during the 4-year period 1970-1973 as described in Appendix A. The second was a comparison of slack after flood values computed from the 3-day salinity data also described in Appendix A. The following procedure was used to determine the prototype slack after flood salinity. Prototype salinity data were collected during daylight (approximately 13 hr per day) for three consecutive days. The starting time of each data series was adjusted so that time-zero corresponded to the moon's crossing of the Greenwich meridian (lunar zero). This yielded three independent, comparable-in-time, data sets. After spurious and anomalous data were removed, an average salinity was calculated for each lunar-based hour by merely averaging those values that corresponded to a given lunar hour. The highest average value during the tidal cycle was then used to indicate the salinity corresponding to slack after flood. These two types of slack salinity data were then used for model-prototype comparison.

75. Two separate tests were run on the model for salinity verification. The first test (Hydrograph III) covered the prototype period of 29 September 1971 through 23 October 1973. The majority of the main bay salinity measurements were taken during this period. The second test (Hydrograph IV) covered the period of 17 October 1969 through 11 February 1972 and included both the main bay and most of the tributaries. These two tests covered all prototype data gathering periods. Freshwater inflow for salinity verification was provided by the reproduction of the prototype inflow hydrographs at the 21 inflow locations for the years in which each test was run. Summary annual hydrographs for the James, Potomac, and Rappahannock Rivers and the total bay inflow are shown in Appendix D in Plates D1-D4. Values for each inflow are on file at WES. Two-week-average hydrograph values were reproduced at each inflow location for Hydrographs III and IV. In order to reproduce a spring-neap cycle of the ocean tide, a 28-day tidal period was selected from raw tidal data at sta 3 for the period of 28 August 1973 at 0900 to 25 September 1973 at 0730. This period was selected as a representative period of well-defined spring and neap conditions. This tidal record was filtered

to remove the long-period component due to wind stress. Figure 32 shows a plot of the filtered sta 3 tide. This tide was adjusted at the tide generator in such a manner that the tide of Figure 32 was reproduced at sta 3 in the model. A 12-constituent tide was constructed for Reedy Point (sta 75) for the same period from the individual astronomical constituents since tide data were not available for the particular period used for sta 3. A plot of this tide is shown in Figure 33. Both tides were continuously repeated at the respective tide generators for the duration of each test. Specific details of boundary control during Hydrographs III and IV may be found in Acres American Hydrograph III Boundary Control Report (Dyok 1978) and Hydrograph IV Boundary Control Report (Bridgeman 1978a).

76. As previously stated, reproduction of the wind-field effects on the bay was not possible. In order to simulate the additional mixing caused by wind stress, a bubbler system was installed in the model. This system consisted of perforated Tygon tubing placed along the axis of the bay and major tributaries as described in paragraph 30. The introduction of this system was found to be imperative as will be discussed in paragraph 81.

77. Presentation of salinity verification comparisons are limited to the same slack salinity prototype data. Two types of comparisons were made to best represent the degree of model reproduction of the prototype system. These data are included in Appendix D. The first comparisons are in the form of time-history salinities for the surface, middepth, and bottom measurements for each major salinity station (see Figure 4). Plates D5-D39 represent the main bay and tributary data taken during Hydrograph IV. Plates D40-D50 represent the main bay data of Hydrograph III. In all plots, the freshwater inflow hydrograph, which was reproduced on the model, is shown below the time-histories of the salinity values. The second comparison is that of model and prototype isohalines up the axis of the bay during Hydrograph III. Each plot (Plates D51-D61) represents the model-prototype comparison for the lunar day indicated on which prototype data were collected. Lunar days, equaling 24.84 hr, were used in the salinity plots for ease of comparison with

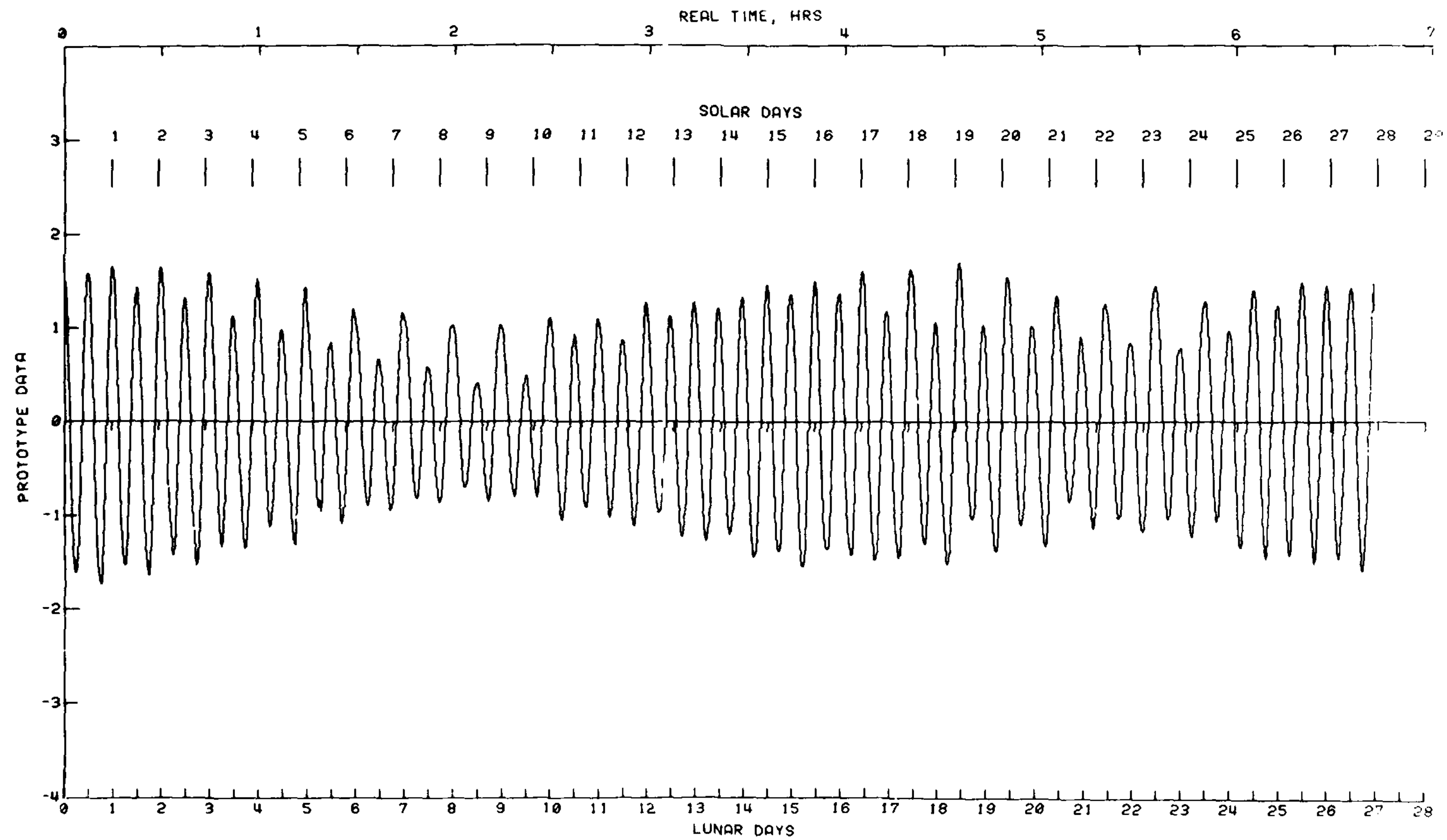



Figure 32. Sta 3, 28-day source tide (filtered) for period of 28 August 1973 at 0900 to 25 September 1973 at 0730

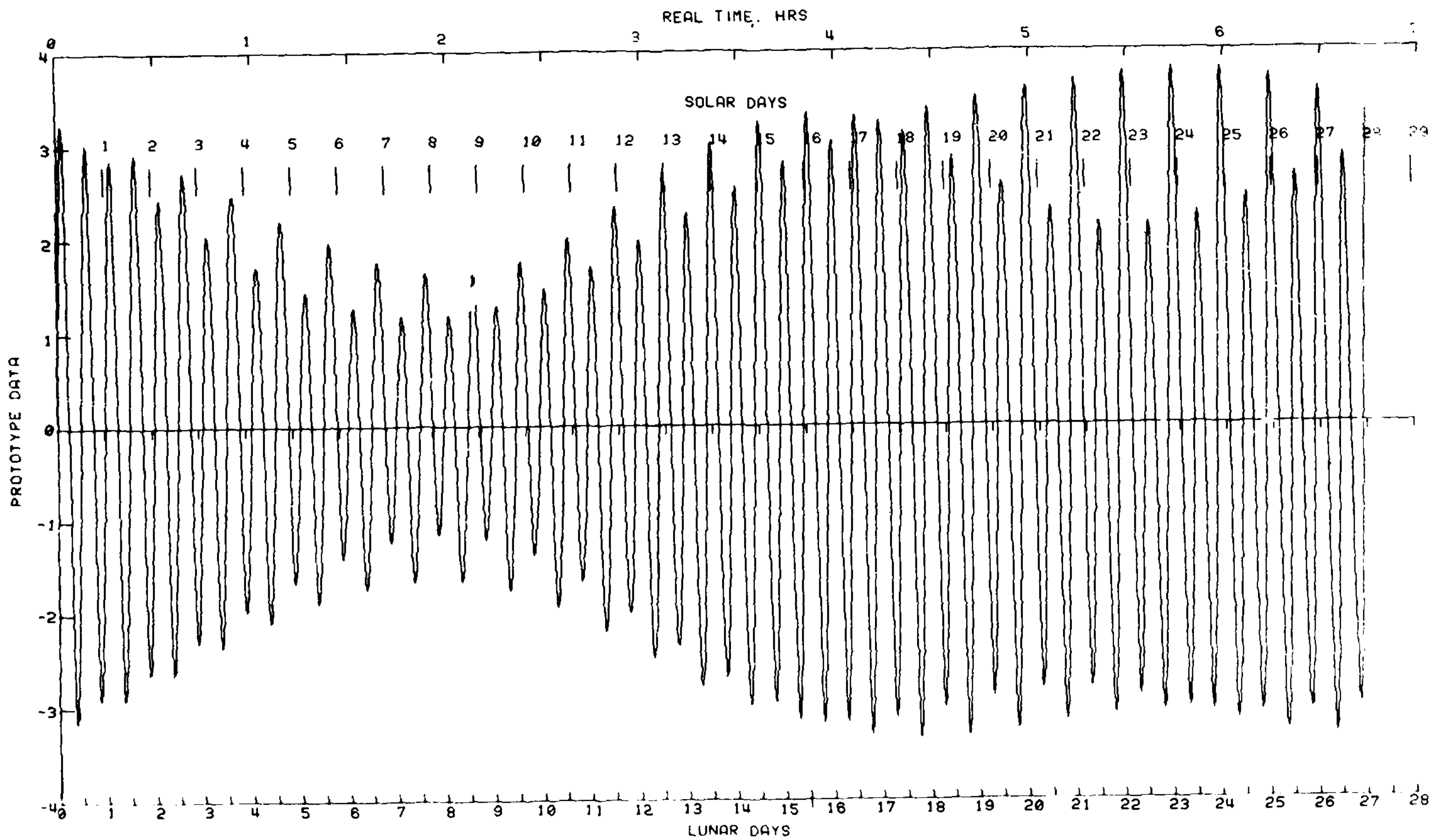



Figure 33. Reedy Point (sta 75), 28-day tide (constructed from 12 tidal constituents) for period of 28 August 1973 at 0900 to 25 September 1973 at 0730

prototype data, which were given in lunar days equivalent to the particular tidal cycle corresponding to when the same slack salinity data were taken. Lunar day zero on Plates D5-D39 represents 17 October 1969 while lunar day zero on Plates D40-D50 represents 29 September 1971. Model-prototype data comparisons and raw data not included in this report are on file at WES.

## Reliability of Verification

78. Limitations of the prototype data have been pointed out in Appendix A and in this report. An assessment of those conclusions is necessary so that a proper evaluation of model verification can be made.

79. Prototype tidal height data were excellent for the tidal height verification phase of the model. As pointed out in paragraph 61, model-prototype comparisons were excellent since the effects of wind stress could be essentially removed. Preliminary datum plane difficulties were resolved by confirming the work by Edge (1959) and Sturges (1967). Figures 29 and 30 show that the model mean tide level slope and datum are essentially those of the prototype. Calculations, based on data from Table 6, show that 98.4 percent of the model tidal height data arrival times are within $\pm 1/2$ hr of the prototype data arrival times, and the maximum error was about 1.3 hr at the upper end of the Rappahannock River. Similar calculations show that 78.1 percent of the model tidal data amplitudes are within a $\pm 10$ percent deviation from the prototype amplitudes and that 92.2 percent were within a $\pm 20$ percent deviation. If the lower bay eastern shore tide stations are discounted, the percentages increase to 84.7 percent and 96.6 percent, respectively. The maximum amplitude error was about 0.7 ft just inside the bay entrance. The MTL - SLD difference was generally less than $\pm 0.2$ ft, with a maximum difference of about 0.5 ft on the western shore near the mouth of the Patuxent River. Model reproduction of tidal amplitudes, phase angles, and datums shows that an extremely reliable tidal height verification was achieved.

80. Prototype velocity data were considered acceptable for the $M_2$

verification approach. The methods employed to compute prototype $M_2$ velocity amplitude and phase angle yielded adjustment factors for both wind and no-wind conditions. Velocity amplitudes computed from these factors were considered as good as could be obtained from the available data. Prototype velocity phase angles were considered very good. Average $M_2$ velocities (indicative of predominance of flow) could not be reliably determined from the existing prototype data. The precise effect of wind fields on a short-term velocity record for a given depth is not known; however, since the wind fields have a cycle time of approximately the same period as the length of data, it is assumed that the wind effects on the predominance of flow would tend to cancel out. Predominance of flow comparisons were qualitatively made based on Tables 7 and 8; however, individual comparisons cannot and should not be made. Model reproduction of tidal velocity amplitudes and phase angles was considered acceptable even though areas of moderate deviation did exist. In many cases, prototype data were inconsistent with prototype data from adjacent velocity ranges and were probably in error. In other cases, differences resulted from the difficulties of reducing poor quality raw prototype data to an $M_2$ prototype value. Calculations, based on main bay data from Table 7, show that 84.1 percent of the model velocity arrival times are within $\pm 1$ hr of the prototype velocity arrival times and 55.6 percent are within $\pm 1/2$ hr of the prototype arrival times. The maximum velocity phase difference (discounting obvious bad data) was about 2 hr on the eastern end of Range CB03 (near the Pocomoke River). Further calculations show that 82.5 percent of the main bay velocity amplitudes deviated less than $\pm 35$ percent of the prototype values and 52.4 percent were within a $\pm 20$ percent deviation of the prototype values. The maximum velocity amplitude error was about 1.2 fps at stations near the western ends of Ranges CB02 and CB06. In view of the fact that the prototype velocities in Chesapeake Bay are small (usually under 2 fps), the model was considered well verified for velocities.

81. Salinity prototype data were the least reliable data used for model verification. It is known that wind fields have a substantial effect on the behavior of the bay. These effects were either removed or

accounted for in the analyses of prototype tidal height and tidal velocity data; however, the effect on salinity distribution cannot be evaluated. Large-scale density circulations of unknown duration could easily be due only to wind stress. Wind effects and the duration of those effects are unknown but they are included in the short, discontinuous raw data series. Repeated attempts at variation of roughness were made in an attempt to reproduce the salinity distribution. Tidal plane changes were also made. Even though these changes sacrificed tidal height and velocity verification, the effects on the salinity distribution remained negligible. The fact that the prototype data indicated substantially more mixing than the model was capable of producing under only tidal and freshwater inflow boundary conditions led to the conclusion that an external mixing mechanism would be necessary to obtain a good model-prototype salinity comparison.

82. Roughness distribution and tidal plane were returned to the conditions of tidal height and velocity verification. The bubbler system was then introduced into the model to reduce model stratification by the additional vertical mixing caused by the rising bubbles. By this method, an overall salinity distribution was achieved that agreed with the prototype data.

83. Individual model-prototype salinity data comparisons range from excellent to poor. These comparisons do not provide a fair evaluation of the capabilities of the model and are not included in this report. Only by looking at the total model salinity distribution, both vertically and horizontally, and the response to tidal changes and freshwater inflow changes can the model be properly judged. The fact that the model temporal response to tides and inflow fluctuations is very similar to that of the prototype can readily be seen in Plates D5-D50 of Appendix D. The spatial response of the model is also very similar to the prototype, as evidenced in Plates D51-D61 of Appendix D. The fact that the model was also able to reproduce extreme events certainly demonstrates the flexibility and accuracy of the model. This was shown during the running of Hydrograph III during which time Hurricane Agnes crossed the Chesapeake Bay area. The response of both the model and the

prototype can be seen in Plates D40-D50 of Appendix D at approximately lunar day 280 (corresponding to the hurricane of 21-22 June 1972). Although the biweekly hydrograph steps in the model do not produce the same instantaneous effect on the model that several days of extreme flow have on the prototype, it can be seen that the salinity trends and distributions were reproduced very well by the model. In view of these comparisons, and the available prototype data, the model is considered verified for salinity conditions.

## Coriolis Force

84. The Coriolis force mentioned in the introduction of this report also represents a "real" force acting on the bay. These effects have not yet been discussed since it is not economically feasible to reproduce them on the model. Unlike wind, however, these forces and the resulting effect can be anticipated. The following analysis will demonstrate the impact of the omission of these forces.

85. Coriolis force is the apparent force that results from the rotation of the earth about its polar axis. A solution for the tidal amplitude and horizontal velocity (including Coriolis effects) was given by Lord Kelvin (Sverdrup, Johnson, and Fleming 1942) for the idealized case of a constant width, constant depth, north-south oriented channel using a frictionless fluid. This solution was:

$$U = \eta\sqrt{\frac{g}{h}} \tag{15}$$

$$V = 0 \quad \text{(solution based on one-dimensional system)} \tag{16}$$

$$\eta = \eta_o e^{-\frac{(2\omega \sin \phi y)}{c}} \cos\left(\sigma t - \frac{\sigma}{cx}\right) \tag{17}$$

where

- $U$ = horizontal velocity, $x$ (longitudinal) direction
- $\eta$ = water-surface elevation change caused by Coriolis force and measured from mean water level

$h$ = total depth of flow, ft

$V$ = horizontal velocity, $y$ (lateral) direction

$n_o$ = unadjusted tidal amplitude

$\omega$ = angular velocity of the earth

$\phi$ = latitude in northern hemisphere

$y$ = width of channel, east-west

$c = \sqrt{gh}$ = celerity of shallow-water gravity wave

$\sigma$ = angular velocity of wave

The solution of this equation yields an approximate estimate of the effect of Coriolis force on the tidal amplitudes and velocities across Chesapeake Bay. An approximate maximum width of the bay of 20 miles should be used to correspond to the idealization of constant width. (Note that the island chain extending into the lower portion of the bay effectively channelizes much of the lower bay.) An average depth of 30 ft and a latitude of 38 deg can be used. Computations then indicate a reduction in tidal amplitude and velocity east to west of about 26.2 percent for the lower portion of the bay. Upper reaches of the bay would reflect a much lower reduction (i.e., a 12.6 percent reduction at latitude 39 deg, width of 10 miles, and depth of 40 ft).

86. Variations of this magnitude can be seen in comparisons of the prototype $M_2$ tidal amplitude of eastern shore and western shore tide stations (Table 3). Comparisons of model-prototype tide height data show corresponding discrepancies resulting from the lack of sufficient Coriolis force in the model. The impact of these effects is minimized, however, due to the low amplitude tides of Chesapeake Bay. For instance, the maximum reduction in tidal height amplitude from eastern shore to western shore (as calculated) is only about 0.40 ft at a latitude corresponding to sta 22 and 0.20 ft at a latitude corresponding to sta 34. The effect of Coriolis force on tidal velocities should reflect a decrease in amplitude from east to west of the same percentage as that of the tidal height amplitudes (Equation 15). These effects are not seen in the prototype velocity data, however. A possible explanation for this observation is that the geometry and bathymetry of the lower bay

area produce a significantly greater influence on velocities than the Coriolis force. The length of prototype data does not permit an evaluation of this possibility. Although the physical model does not reproduce the properly scaled Coriolis force, it does acceptably reproduce tidal heights, tidal velocities, and salinity distributions. For this reason, and the previous calculations, it is reasonable to conclude that Coriolis force is not a governing force in the bay.

## PART VI: CONCLUSIONS

87. The Chesapeake Bay model has been verified to acceptably reproduce tidal heights, tidal velocities, and salinity distributions. This has been accomplished in the following two phases:

- a. Tidal height and tidal velocity verification was achieved by reproduction of the primary lunar astronomical constituent and steady-state inflows. Boundary conditions for this phase of verification included an $M_2$ source tide at the model ocean and at the C&D Canal, an ocean salinity of 31 ppt (Test 20) and 30 ppt (Test 22), a C&D Canal salinity of 3 to 5 ppt, and a long-term average freshwater inflow at each of the 21 inflow locations on the model.
- b. Salinity verification was achieved by the reproduction of a typical 28-day tide sequence, filtered to remove long-period (wind-generated) energy, and long-duration inflow hydrographs. Boundary conditions for this phase included a 28-day ocean tide, a 28-day C&D Canal tide, an ocean salinity of 30 ppt, a C&D Canal salinity of 3 to 5 ppt, freshwater inflow hydrographs at the 21 major tributaries of the bay, and a bubbler system to statistically reproduce the additional mixing caused by wind stress on the bay.

88. A vast amount of time and manpower was expended to ensure the best possible verification of the Chesapeake Bay model. The fact that the model was the largest physical estuarine model ever built presented many problems which had to be overcome. The difficulties posed by the physical size of the model were solved by an innovative computer control and monitoring system employing instrumentation developed specifically for the environmental conditions of the model. Problems were encountered, because of the lack of synoptic prototype data, that made conventional model verification procedures impossible. These problems were further complicated by the existence of a substantial amount of wind contamination in the prototype data. The use of digital filtering techniques and the subsequent verification of the model to tidal constituents solved these problems. Numerous model tests were conducted to ensure that the procedures used for verification were valid and would produce a model that was verified to prototype conditions. The unavoidable conclusion is that the model is well verified and can be used to

reliably predict the effects of future changes in the bay system on tidal heights, velocity distributions, and salinity distributions of the bay. The model will not, and was not intended to, reproduce the effects of wind-induced surges on the tides, velocities, or salinities; however, the impact of future changes should be based on the deviation from normal conditions instead of extreme conditions. The model can now be used as the predictive tool it was designed to be.

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Table 1

Stations and Periods of Wind Data

| No. | Location | Periods of Collection | | | | | |
|---|---|---|---|---|---|---|---|
| | | Jun-Nov 1970 | Apr-Aug 1971 | Oct 1971 | Oct 1972 | Apr-May 1972 | Jul-Aug 1972 |
| 1 | Chesapeake Light Station | Yes | Yes | Yes | Yes | Yes | Yes |
| 2 | Oceana, Va.-NAS | Yes | Yes | Yes | Yes | Yes | Yes |
| 3 | Norfolk, Va.-WSO | Yes | Yes | Yes | Yes | Yes | Yes |
| 4 | Norfolk, Va.-USFWC | Continuous record Jun 1970-Dec 1972 | | | | | |
| 5 | Langley AFB, Va. | Yes | Yes | Yes | Yes | Yes | Yes |
| 6 | Newport News, Va. | Yes | Yes | Yes | Yes | Yes | Yes |
| 7 | Felker AAF, Va. | Yes | Yes | Yes | No | No | No |
| 8 | Richmond, Va.-WSO | Yes | Yes | Yes | No | No | No |
| 9 | Wolf Trap Light Station | Yes | Apr-Jul | No | No | No | No |
| 10 | Smith Point, Va. | Yes | Yes | No | No | No | No |
| 11 | Crisfield, Md.-USCG | Jun-Aug, Oct | No | Yes | No | Yes | Yes |
| 12 | Patuxent NAS, Md. | Continuous record Jun 1970-Dec 1972 | | | | | |
| 13 | Cove Point, Md. | Jun-Aug | No | No | Yes | Yes | Yes |
| 14 | Quantico MCAS, Va. | Yes | Yes | Yes | Yes | Yes | Yes |
| 15 | Davidson AAF, Va. | Yes | Yes | Yes | Yes | Yes | Yes |
| 16 | Andrews AFB, Va. | Yes | Yes | Yes | Yes | Yes | Yes |
| 17 | National Airport, Washington, D. C. | Yes | Yes | Yes | Yes | Yes | Yes |
| 18 | Salisbury, Md.-FAA | Yes | Yes | Yes | Yes | Yes | Yes |
| 19 | Thomas Point, Md.-USCG | Yes | Yes | Yes | Yes | Yes | Yes |
| 20 | Tipton AAF, Md. | Yes | Yes | Yes | No | No | No |
| 21 | BWI, Baltimore, Md. | Yes | Yes | Yes | Yes | Yes | Yes |
| 22 | Philips AAF, Md. | Weekday readings only for Jun 1970-Dec 1972 | | | | | |
| 23 | Wallops Island, Va. | Yes | Yes | Yes | Yes | Yes | Yes |
| 24 | Ocean City, Md. | Yes | Yes | Yes | Yes | Yes | Yes |

Table 2

Tide and Wind Station Data Used in Low-Frequency Energy Analysis

| 3 April-28 May 1971 | 3 July-28 August 1971 | 4 October-28 October 1971 |
|---|---|---|
| | Tide Stations | |
| 3 - Old Point Comfort | 3 - Old Point Comfort | 3 - Old Point Comfort |
| 18 - Glouster Point | 18 - Glouster Point | 26 - Mill Creek |
| 36 - Fleet Point | 36 - Fleet Point | 64 - Love Point |
| 38 - Lewisetta | 53 - Solomans Island | 63 - Gingerville Creek |
| 53 - Solomons Island | 73 - Annapolis | |
| 73 - Annapolis | | |
| | Wind Stations | |
| Norfolk | Norfolk | Norfolk |
| Patuxent | Patuxent | Patuxent |
| Smith Point | Smith Point | Newport News |
| Baltimore | Baltimore | Baltimore |

Table 3

Astronomical Amplitude, ft, for Stations

| Constituent | Old Point Comfort No. 3 | Fleet Point No. 36 | Matapeake No. 62 | Harve De Grace No. 72 |
|---|---|---|---|---|
| $M_2$ | 1.188 | 0.518 | 0.460 | 0.826 |
| $N_2$ | 0.230 | 0.093 | 0.077 | 0.127 |
| $S_2$ | 0.265 | 0.112 | 0.095 | 0.148 |
| $\nu_2$ | 0.051 | 0.023 | 0.026 | 0.063 |
| $\mu_2$ | 0.041 | 0.011 | 0.006 | 0.002 |
| $(2N)_2$ | 0.032 | 0.011 | 0.013 | 0.028 |
| $\lambda_2$ | 0.023 | 0.008 | 0.011 | 0.017 |
| $T_2$ | 0.011 | 0.009 | 0.005 | 0.032 |
| $R_2$ | 0.003 | 0.001 | 0.006 | 0.008 |
| $(2SM)_2$ | 0.009 | 0.002 | 0.002 | 0.007 |
| $L_2$ | 0.003 | 0.025 | 0.022 | 0.054 |
| $K_2$ | 0.059 | 0.027 | 0.020 | 0.027 |
| $M_2$ energy | 91.3 percent | 92.0 percent | 92.6 percent | 93.4 percent |

Table 4

Prototype $M_2$ Constituent Values

| Station | $M_2$ Amplitude ft | $M_2$ Epoch deg | MTL-SLD ft | Station | $M_2$ Amplitude ft | $M_2$ Epoch deg | MTL-SLD ft |
|---|---|---|---|---|---|---|---|
| 01 | 1.588 | 211.470 | -0.09 | 41* | 0.796 | 47.600 | +0.32 |
| 02 | 1.036 | 251.570 | -0.07 | 42 | 0.757 | 65.130 | +0.27 |
| 03 | 1.188 | 248.02 | -0.04 | 43* | 0.655 | 82.380 | +0.28 |
| 04 | 1.185 | 254.390 | -0.04 | 44 | 0.563 | 101.000 | +0.28 |
| 05 | 1.338 | 260.330 | -0.05 | 45 | 0.510 | 159.100 | +0.28 |
| 06 | 1.387 | 276.430 | -0.06 | 46* | 0.621 | 178.248 | +0.31 |
| 07* | 1.252 | 270.678 | -0.07 | 47 | 0.796 | 190.170 | +0.26 |
| 08 | 1.164 | 290.970 | +0.05 | 48* | 0.989 | 207.095 | +0.37 |
| 09 | 0.884 | 332.810 | +0.09 | 49 | 1.318 | 222.470 | +0.52 |
| 10* | 0.886 | 359.128 | +0.14 | 50* | 0.954 | 29.200 | +0.09 |
| 11 | 0.819 | 2.700 | +0.14 | 51* | 0.967 | 108.440 | +0.11 |
| 12 | 0.958 | 47.450 | +0.14 | 52* | 0.740 | 40.512 | +0.19 |
| 13* | 1.099 | 77.128 | +0.25 | 53 | 0.549 | 45.310 | +0.22 |
| 14 | 1.302 | 107.240 | +0.41 | 54 | 0.645 | 56.080 | +0.27 |
| 15** | -- | -- | -- | 55* | 0.832 | 98.522 | +0.39 |
| 16* | 1.089 | 257.285 | -0.06 | 56 | 0.754 | 68.160 | +0.29 |
| 17 | 1.296 | 239.110 | -0.06 | 57* | 0.616 | 57.540 | +0.55 |
| 18 | 1.155 | 260.190 | -0.03 | 58 | 0.586 | 88.730 | +0.31 |
| 19 | 1.185 | 272.360 | -0.03 | 59 | 0.456 | 101.540 | +0.32 |
| 20 | 1.354 | 298.190 | -0.06 | 60 | 0.767 | 105.960 | +0.19 |
| 21 | 1.295 | 315.190 | +0.01 | 61 | 0.792 | 158.870 | +0.26 |
| 22 | 1.142 | 250.790 | -0.01 | 62 | 0.460 | 140.210 | +0.24 |
| 23** | -- | -- | +0.06 | 63** | -- | -- | +0.34 |
| 24* | 0.542 | 301.855 | 0.0 | 64 | 0.527 | 170.170 | +0.29 |
| 25* | 0.806 | 309.610 | -0.08 | 65** | -- | -- | +0.34 |
| 26 | 0.589 | 320.980 | 0.03 | 66 | 0.892 | 201.790 | +0.38 |
| 27 | 0.699 | 341.170 | +0.14 | 67 | 0.450 | 183.670 | 0.34 |
| 28 | 0.795 | 358.330 | +0.26 | 68 | 0.486 | 185.150 | 0.37 |
| 29 | 0.834 | 12.480 | +0.32 | 69 | 0.542 | 195.170 | 0.32 |
| 30 | 0.819 | 37.790 | +0.23 | 70 | 0.730 | 253.490 | +0.50 |
| 31 | 0.693 | 96.770 | +0.37 | 71** | -- | -- | +0.41 |
| 32 | 0.954 | 168.690 | +0.56 | 72 | 0.826 | 281.660 | 0.65 |
| 33 | 1.129 | 189.770 | 0.61 | 73** | -- | -- | +0.35 |
| 34 | 0.552 | 309.630 | 0.0 | 74 | 0.794 | 62.180 | +0.27 |
| 35* | 1.071 | 353.810 | +0.12 | 75 | 1.373 | 299.620 | +0.46 |
| 36 | 0.518 | 339.040 | +0.09 | | | | |
| 37* | 0.593 | 18.562 | +0.16 | | | | |
| 38 | 0.592 | 22.350 | +0.17 | | | | |
| 39** | -- | -- | +0.15 | | | | |
| 40* | 0.688 | 34.340 | +0.35 | | | | |

* As computed from 29-day harmonic analysis.
** Harmonic analysis was not provided.

Table 5

Average Long-Term Freshwater Discharge

| Inflow No. | Flow cfs | Inflow No. | Flow cfs | Inflow No. | Flow cfs |
|---|---|---|---|---|---|
| 1 | 700 | 8 | 2,452 | 15 | 38,500 |
| 2 | 300 | 9 | 602 | 16 | 400 |
| 3 | 1,000 | 10 | 7,964 | 17 | 519 |
| 4 | 7,500 | 11 | 911 | 18 | 196 |
| 5 | 2,750 | 12 | 299 | 19 | 845 |
| 6 | 2,940 | 13 | 684 | 20 | 1,675 |
| 7 | 426 | 14 | 880 | 21 | 1,031 |

Note: Total bay inflow = 72,574 cfs.

Table 6

Model (M) and Prototype (P) Tide Data, Test 20, 27-31 March 1978

| Station | $M_2$ Amplitude, ft | | | MTL-SLD, ft | | | Epoch, deg* | | |
|---|---|---|---|---|---|---|---|---|---|
| | M | P | Difference | M | P | Difference | M | P | Difference |
| | | | | James River | | | | | |
| 3 | 1.17 | 1.19 | -0.02 | -0.10 | -0.04 | -0.06 | 249 | 248 | 1 |
| 4 | 1.22 | 1.19 | 0.03 | -0.11 | -0.03 | -0.08 | 254 | 254 | -1 |
| 5 | 1.39 | 1.34 | 0.05 | +0.02 | -0.03 | -0.01 | 260 | 260 | -1 |
| 6 | 1.44 | 1.39 | 0.05 | 0.10 | -0.04 | 0.06 | 285 | 276 | -1 |
| 7 | 1.23 | 1.25 | -0.02 | -0.09 | -0.07 | -0.02 | 270 | 271 | 0 |
| 8 | 1.04 | 1.16 | -0.12 | 0.08 | 0.04 | 0.04 | 296 | 291 | 5 |
| 9 | 0.88 | 0.88 | 0.00 | 0.12 | 0.07 | 0.05 | 345 | 333 | 12 |
| 10 | 0.87 | 0.89 | -0.02 | 0.08 | 0.11 | -0.03 | 13 | 359 | 14 |
| 11 | 0.80 | 0.82 | -0.02 | 0.17 | 0.11 | 0.06 | 12 | 3 | 9 |
| 12 | 0.91 | 0.96 | -0.05 | 0.24 | 0.10 | 0.14 | 56 | 47 | 8 |
| 13 | 1.09 | 1.10 | -0.01 | 0.43 | 0.21 | 0.22 | 86 | 77 | 9 |
| 14 | 1.31 | 1.30 | 0.01 | 0.42 | 0.37 | 0.05 | 118 | 107 | 11 |
| | | | | York River | | | | | |
| 16** | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18** | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 19 | 1.17 | 1.19 | -0.02 | -0.04 | -0.06 | +0.02 | 277 | 272 | 5 |
| 20 | 1.27 | 1.35 | -0.08 | -0.10 | -0.11 | +0.01 | 30 | 298 | 3 |
| 21** | | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | Rappahannock River | | | | | |
| 26 | 0.66 | 0.59 | 0.07 | -0.05 | -0.04 | -0.01 | 325 | 321 | 4 |
| 27 | 0.74 | 0.70 | +0.04 | -0.12 | 0.07 | -0.19 | 340 | 341 | -1 |
| 28 | 0.77 | 0.80 | -0.03 | 0.02 | 0.17 | -0.15 | 356 | 358 | -3 |
| 29 | 0.78 | 0.83 | -0.05 | 0.07 | 0.22 | -0.15 | 24 | 12 | 12 |
| 30 | 0.79 | 0.82 | -0.03 | -0.10 | 0.12 | -0.22 | 43 | 38 | 5 |
| 31 | 0.73 | 0.69 | 0.04 | 0.14 | 0.25 | -0.11 | 99 | 97 | 2 |
| 32** | | -- | -- | -- | -- | -- | -- | -- | -- |
| 33 | 0.59 | 1.13 | -0.54 | 0.90 | 0.47 | 0.43 | 228 | 190 | 39 |
| | | | | Potomac River | | | | | |
| 37 | 0.62 | 0.59 | 0.03 | -0.09 | 0.04 | -0.13 | 24 | 19 | 6 |
| 38 | 0.64 | 0.59 | 0.05 | 0.17 | 0.06 | 0.11 | 27 | 22 | 4 |
| 40 | 0.73 | 0.69 | 0.04 | -0.04 | 0.22 | -0.26 | 38 | 34 | 4 |
| 41 | 0.80 | 0.80 | 0.00 | -0.08 | 0.18 | -0.26 | 54 | 48 | 7 |
| 74 | 0.84 | 0.79 | 0.05 | 0.10 | 0.13 | -0.03 | 73 | 62 | 11 |
| 42 | 0.78 | 0.76 | 0.02 | 0.03 | 0.12 | -0.09 | 76 | 65 | 11 |
| 43 | 0.65 | 0.66 | -0.01 | -0.05 | 0.11 | -0.16 | 95 | 82 | 12 |
| 44 | 0.57 | 0.56 | 0.01 | 0.01 | 0.12 | -0.10 | 115 | 101 | 14 |
| 45 | 0.59 | 0.51 | 0.08 | 0.09 | 0.12 | -0.03 | 170 | 159 | 11 |
| 46 | 0.67 | 0.62 | 0.05 | 0.08 | 0.14 | -0.06 | 183 | 178 | 5 |
| 47 | 0.82 | 0.80 | 0.02 | 0.09 | 0.08 | 0.01 | 199 | 190 | 8 |
| 48 | 1.01 | 0.99 | 0.02 | -0.02 | 0.18 | -0.20 | 214 | 207 | 7 |
| 49 | 1.39 | 1.32 | 0.07 | 0.17 | 0.31 | -0.14 | 234 | 222 | 12 |

(Continued)

* 28.98 deg = 1 hr.

** Model data were not taken.

Table 6 (Concluded)

| Station | $M_2$ Amplitude, ft | | | MTL-SLD, ft | | | Epoch, deg | | |
|---|---|---|---|---|---|---|---|---|---|
| | M | P | Difference | M | P | Difference | M | P | Difference |
| | | | | Patuxent River | | | | | |
| 53 | 0.56 | 0.55 | 0.01 | 0.00 | 0.07 | -0.07 | 51 | 45 | 6 |
| 54 | 0.66 | 0.65 | 0.01 | 0.08 | 0.11 | -0.03 | 57 | 56 | 1 |
| 55** | | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | 0.83 | 0.75 | 0.08 | -0.05 | +0.12 | -0.17 | 70 | 68 | 2 |
| | | | | Eastern Shore Rivers | | | | | |
| 66 | 0.75 | 0.89 | -0.14 | 0.04 | 0.13 | -0.09 | 212 | 202 | 11 |
| 58 | 0.54 | 0.59 | -0.04 | -0.14 | 0.07 | -0.21 | 97 | 89 | 8 |
| 60 | 0.73 | 0.77 | -0.04 | -0.05 | 0.01 | -0.06 | 112 | 106 | 7 |
| 61 | 0.75 | 0.79 | -0.04 | 0.06 | 0.06 | 0.00 | 170 | 159 | 12 |
| | | | | Lower Bay and Eastern Shore | | | | | |
| 17 | 0.59 | 1.30 | -0.71 | -0.03 | -0.08 | +0.05 | 236 | 239 | -3 |
| 25 | 0.69 | 0.81 | -0.12 | -0.08 | -0.14 | +0.06 | 312 | 309 | 3 |
| 35 | 0.91 | 1.07 | 0.16 | -0.06 | 0.02 | -0.08 | 1 | 354 | 7 |
| 52 | 0.64 | 0.74 | -0.10 | -0.06 | 0.04 | -0.10 | 39 | 40 | -2 |
| 50 | 0.62 | 0.95 | -0.33 | -0.11 | -0.04 | -0.07 | 52 | 29 | 23 |
| 51 | 0.97 | 0.97 | 0.00 | 0.09 | -0.06 | 0.15 | 116 | 108 | 8 |
| | | | | Upper Bay and Western Shore | | | | | |
| 1 | 1.41 | 1.59 | -0.18 | -0.20 | -0.07 | -0.13 | 213 | 211 | 2 |
| 2 | 1.04 | 1.04 | 0.00 | -0.26 | -0.13 | -0.13 | 257 | 252 | 6 |
| 22 | 1.10 | 1.14 | -0.04 | -0.19 | -0.06 | -0.13 | 258 | 251 | 8 |
| 24 | 0.62 | 0.54 | 0.08 | -0.17 | -0.06 | -0.10 | 304 | 302 | 3 |
| 34 | 0.58 | 0.55 | 0.03 | -0.09 | -0.07 | -0.02 | 318 | 310 | 9 |
| 36 | 0.58 | 0.52 | 0.06 | -0.11 | 0.00 | -0.11 | 339 | 339 | 1 |
| 57 | 0.48 | 0.62 | -0.14 | -0.07 | 0.39 | -0.46 | 57 | 57 | -0 |
| 59 | 0.46 | 0.46 | 0.00 | -0.08 | 0.13 | -0.21 | 98 | 101 | -3 |
| 62 | 0.42 | 0.46 | -0.04 | -0.05 | 0.02 | -0.07 | 148 | 140 | 7 |
| 64 | 0.48 | 0.53 | -0.05 | 0.10 | 0.06 | 0.04 | 176 | 170 | 6 |
| 67 | 0.48 | 0.45 | 0.03 | 0.09 | 0.09 | 0.00 | 185 | 181 | 2 |
| 68 | 0.53 | 0.49 | 0.04 | 0.07 | 0.11 | -0.04 | 187 | 185 | 2 |
| 69 | 0.51 | 0.54 | -0.03 | -0.04 | 0.07 | -0.10 | 200 | 195 | 5 |
| 70 | 0.72 | 0.73 | -0.01 | 0.11 | 0.23 | -0.12 | 263 | 253 | 9 |
| 71 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 72 | 0.84 | 0.83 | 0.01 | 0.26 | 0.35 | -0.09 | 290 | 282 | 8 |
| 75 | 1.31 | 1.37 | -0.06 | 0.00 | 0.17 | -0.17 | 286 | 300 | -14 |

** Model data were not taken.

Table 7

Velocity Verification Test No. 20, 30 March 1978

| | | Prototype | | | | Model | | | | Model-Prototype | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range | Station | Depth ft | Phase | Amplitude | Average* | Depth ft | Phase | Amplitude | Average* | Phase | Amplitude |
| CB00 | 1 | 3 | 276.930 | 2.343 | -0.930 | 5 | 252.384 | 1.397 | -0.728 | -24 | -0.95 |
| CB00 | 1 | 32 | 227.190 | 1.546 | -0.420 | 52 | 210.701 | 1.566 | 0.224 | -17 | 0.02 |
| CB00 | 2 | 3 | 286.860 | 2.020 | -0.410 | 4 | 248.761 | 1.398 | -0.534 | -38 | -0.63 |
| CB00 | 2 | 22 | 270.630 | 2.158 | 0.230 | 20 | 244.066 | 1.480 | 0.135 | -26 | -0.67 |
| CB00 | 2 | 42 | 262.190 | 2.135 | 0.440 | 38 | 239.502 | 1.542 | 0.304 | -23 | -0.79 |
| CB00 | 2 | 52 | 255.820 | 2.170 | 0.440 | 47 | 236.242 | 1.672 | 0.260 | -19 | -0.50 |
| CB00 | 2 | 72 | 245.790 | 1.189 | 0.250 | 64 | 220.467 | 1.335 | 0.371 | -25 | 0.15 |
| CB00 | 3 | 4 | 270.630 | 0.692 | 0.570 | 4 | 262.135 | 1.640 | -0.775 | -8 | 1.02 |
| CB00 | 3 | 32 | 238.370 | 1.466 | -0.030 | 33 | 237.501 | 1.303 | -0.031 | -1 | -0.16 |
| CB00 | 3 | 38 | 216.430 | 1.027 | 0.030 | 38 | 233.897 | 1.023 | -0.037 | -17 | 0.00 |
| CB00 | 4 | 12 | 243.180 | 2.527 | 0.260 | 12 | 243.295 | 1.485 | -0.244 | 0 | -1.04 |
| CB00 | 4 | 22 | 242.720 | 1.881 | 0.220 | 21 | 221.995 | 1.688 | 0.094 | -21 | -0.20 |
| CB00 | 4 | 30 | 217.340 | 1.212 | 0.150 | 28 | 214.089 | 1.423 | 0.177 | -3 | 0.21 |
| CB00 | 5 | 12 | 214.680 | 1.996 | 0.030 | 12 | 238.635 | 1.981 | -0.195 | 24 | -0.01 |
| CB00 | 5 | 17 | 224.540 | 1.569 | 0.060 | 16 | 230.116 | 1.474 | -0.053 | 6 | -0.09 |
| CB00 | 6 | 3 | 234.610 | 2.458 | -0.100 | 4 | 247.631 | 2.353 | -0.584 | 13 | -0.10 |
| CB00 | 6 | 12 | 239.750 | 1.904 | -0.010 | 14 | 235.510 | 2.012 | -0.191 | -4 | 0.11 |
| CB00 | 7 | 3 | 223.500 | 2.481 | -0.320 | 4 | 244.925 | 2.392 | -0.434 | 21 | -0.09 |
| CB00 | 7 | 12 | 222.770 | 1.846 | -0.120 | 13 | 237.883 | 2.154 | -0.093 | 15 | 0.31 |
| CB00 | 7 | 18 | 217.780 | 1.512 | -0.020 | 17 | 235.998 | 1.891 | -0.013 | 18 | 0.38 |
| CB00 | 8 | 12 | 225.430 | 2.227 | -0.030 | 13 | 244.012 | 2.436 | -0.631 | 19 | 0.21 |
| CB00 | 8 | 22 | 220.170 | 2.193 | 0.070 | 23 | 241.149 | 2.319 | -0.383 | 21 | 0.12 |
| CB00 | 8 | 32 | 214.440 | 1.916 | 0.180 | 33 | 237.451 | 2.218 | -0.059 | 23 | 0.30 |
| CB00 | 8 | 42 | 213.950 | 1.246 | 0.150 | 44 | 229.502 | 1.838 | 0.210 | 16 | 0.59 |
| CB00 | 9 | 17 | 232.450 | 2.573 | -0.030 | 13 | 219.939 | 3.183 | -0.679 | -13 | 0.61 |
| CB01 | 1 | 12 | 256.000 | 0.670 | -0.040 | 9 | 258.204 | 1.020 | -0.029 | 2 | 0.35 |
| CB01 | 2 | 12 | 289.240 | 0.793 | -0.160 | 10 | 276.880 | 1.275 | -0.181 | -13 | 0.48 |
| CB01 | 2 | 22 | 259.720 | 0.480 | -0.020 | 18 | 261.025 | 0.846 | 0.048 | 2 | 0.36 |
| CB01 | 3 | 12 | 280.440 | 0.838 | -0.100 | 9 | 271.770 | 1.268 | -0.251 | -9 | 0.43 |
| CB01 | 3 | 22 | 277.480 | 0.715 | 0.020 | 17 | 261.360 | 1.161 | -0.060 | -16 | 0.45 |
| CB01 | 4 | 12 | 276.360 | 0.905 | -0.090 | 11 | 275.903 | 1.210 | -0.152 | -1 | 0.31 |
| CB01 | 4 | 22 | 279.980 | 0.760 | 0.060 | 20 | 268.121 | 1.178 | -0.083 | -11 | 0.41 |
| CB01 | 5 | 12 | 284.470 | 1.865 | -0.110 | 11 | 276.892 | 1.586 | 0.159 | -8 | -0.28 |
| CB01 | 5 | 37 | 251.530 | 0.693 | 0.240 | 35 | 241.418 | 0.923 | 0.200 | -10 | 0.23 |
| CB01 | 6 | 12 | 290.210 | 2.033 | -0.020 | 12 | 276.863 | 1.653 | 0.218 | -14 | -0.38 |
| CB01 | 6 | 22 | 272.110 | 1.474 | 0.450 | 21 | 271.637 | 1.402 | 0.206 | -1 | -0.07 |
| CB01 | 7 | 12 | 298.120 | 2.022 | 0.030 | 12 | 274.591 | 1.491 | -0.034 | -24 | -0 53 |
| CB01 | 7 | 22 | 98.150 | 1.028 | -0.080 | 21 | 265.060 | 1.440 | 0.163 | -167 | 0.42 |
| CB01 | 7 | 27 | 269.060 | 0.860 | 0.190 | 24 | 251.294 | 1.090 | 0.126 | -18 | 0.23 |
| CB01 | 8 | 4 | 276.480 | 2.178 | -0.340 | 4 | 267.437 | 1.569 | -0.318 | -9 | -0.61 |
| CB01 | 8 | 14 | 284.460 | 1.955 | 0.000 | 11 | 265.241 | 1.568 | -0.133 | -19 | -0.39 |
| CB01 | 8 | 28 | 260.580 | 1.072 | 0.130 | 23 | 252.692 | 1.288 | 0.092 | -8 | 0.21 |
| CB01 | 9 | 4 | 272.070 | 2.290 | -0.200 | 4 | 270.148 | 1.689 | -0.261 | -2 | -0.61 |
| CB01 | 9 | 12 | 275.430 | 1.999 | -0.040 | 12 | 267.637 | 1.613 | -0.207 | -8 | -0.38 |
| CB01 | 9 | 22 | 284.550 | 1.921 | 0.000 | 21 | 266.215 | 1.396 | -0.067 | -18 | -0.53 |
| CB01 | 9 | 32 | 279.860 | 1.821 | 0.050 | 31 | 264.120 | 1.086 | -0.071 | -15 | -0.74 |
| CB01 | 9 | 42 | 275.960 | 1.832 | 0.260 | 41 | 248.255 | 1.020 | 0.141 | -27 | -0.81 |
| CB01 | 9 | 52 | 261.830 | 1.519 | 0.370 | 51 | 242.425 | 0.876 | 0.009 | -19 | -0.64 |
| CB01 | 9 | 62 | 263.820 | 1.396 | 0.420 | 60 | 213.162 | 0.699 | -0.138 | -50 | -0.70 |
| CB01 | 9 | 72 | 262.970 | 0.938 | 0.260 | 70 | 205.449 | 0.580 | -0.191 | -57 | -0.35 |
| CB01 | 10 | 4 | 259.690 | 2.603 | -0.150 | 4 | 257.583 | 2.101 | -0.376 | -2 | -0.58 |
| CB01 | 10 | 12 | 250.790 | 1.575 | 0.150 | 11 | 254.896 | 2.006 | -0.220 | 4 | 0.43 |
| CB01 | 10 | 17 | 239.510 | 1.296 | 0.010 | 13 | 251.107 | 1.945 | -0.212 | 12 | 0.65 |
| CB02 | 1 | 4 | 281.240 | 1.374 | -0.250 | 4 | 287.678 | 1.041 | -0.244 | 6 | -0.33 |
| CB02 | 1 | 12 | 284.520 | 1.854 | -0.410 | 10 | 286.791 | 1.126 | -0.218 | 2 | -0.73 |
| CB02 | 1 | 22 | 267.450 | 1.081 | -0.120 | 17 | 274.065 | 0.753 | -0.162 | 7 | -0.33 |
| CB02 | 2 | 4 | 307.470 | 1.641 | 0.110 | 4 | 297.433 | 1.104 | -0.067 | -10 | -0.54 |
| CB02 | 2 | 12 | 311.830 | 2.134 | 0.070 | 10 | 296.159 | 1.258 | -0.045 | -15 | -0.88 |
| CB02 | 2 | 22 | 294.010 | 1.361 | -0.030 | 18 | 282.803 | 1.039 | -0.166 | -12 | -0.33 |
| CB02 | 2 | 27 | 275.650 | 1.201 | -0.060 | 22 | 287.808 | 0.430 | -0.001 | 12 | -0.77 |
| CB02 | 3 | 4 | 322.000 | 1.627 | -0.070 | 4 | 301.132 | 1.319 | -0.251 | -21 | -0.31 |
| CB02 | 3 | 12 | 312.560 | 1.094 | -0.090 | 11 | 314.796 | 1.342 | -0.174 | 2 | 0.25 |
| CB02 | 3 | 32 | 280.440 | 0.694 | 0.020 | 29 | 285.512 | 0.983 | 0.033 | 5 | 0.29 |

(Continued)

* Positive average velocity indicates a net flood velocity, and negative values indicate ebb.

(Sheet 1 of 4)

Table 7 (Continued)

| Range | Station | Prototype Depth ft | Prototype Phase | Prototype Amplitude | Prototype Average | Model Depth ft | Model Phase | Model Amplitude | Model Average | Model-Prototype Phase | Model-Prototype Amplitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CB02 | 4 | 4 | 301.350 | 1.081 | -0.140 | 4 | 301.905 | 1.506 | -0.221 | 0 | 0.42 |
| CB02 | 4 | 22 | 312.190 | 1.094 | -0.120 | 21 | 301.266 | 1.354 | 0.050 | -11 | 0.26 |
| CB02 | 4 | 32 | 266.310 | 0.560 | 0.040 | 31 | 290.000 | 1.002 | 0.069 | 24 | 0.44 |
| CB02 | 5 | 12 | 306.310 | 1.988 | -0.290 | 12 | 308.375 | 1.362 | -0.061 | 2 | -0.62 |
| CB02 | 5 | 22 | 314.030 | 2.121 | 0.020 | 22 | 301.113 | 1.225 | -0.010 | -13 | -0.90 |
| CB02 | 5 | 32 | 290.480 | 1.121 | 0.180 | 32 | 284.227 | 0.887 | 0.036 | -6 | -0.24 |
| CB02 | 6 | 4 | 297.240 | 1.711 | -0.220 | 4 | 306.357 | 1.350 | -0.203 | 9 | -0.36 |
| CB02 | 6 | 12 | 303.090 | 1.700 | -0.130 | 11 | 306.623 | 1.412 | -0.060 | 3 | -0.29 |
| CB02 | 6 | 32 | 286.810 | 1.748 | 0.130 | 31 | 299.836 | 1.065 | 0.230 | 13 | -0.68 |
| CB02 | 6 | 42 | 283.910 | 0.824 | 0.220 | 38 | 286.518 | 0.793 | 0.162 | 3 | -0.03 |
| CB02 | 7 | 4 | 331.470 | 1.561 | -0.110 | 4 | 303.077 | 1.227 | -0.334 | -28 | -0.34 |
| CB02 | 7 | 12 | 302.290 | 2.161 | -0.130 | 11 | 306.924 | 1.323 | -0.193 | 4 | -0.84 |
| CB02 | 7 | 22 | 300.240 | 2.161 | 0.270 | 20 | 305.029 | 1.294 | 0.000 | 5 | -0.87 |
| CB02 | 7 | 32 | 296.710 | 1.814 | 0.290 | 30 | 302.603 | 1.268 | 0.266 | 6 | -0.55 |
| CB02 | 7 | 42 | 291.880 | 1.627 | 0.100 | 39 | 292.646 | 1.206 | 0.163 | 1 | -0.42 |
| CB02 | 7 | 42 | 291.880 | 1.627 | 0.100 | 44 | 281.775 | 0.806 | 0.172 | -10 | -0.82 |
| CB02 | 8 | 4 | 315.710 | 1.627 | -0.120 | 4 | 308.528 | 0.707 | -0.049 | -7 | -0.92 |
| CB02 | 8 | 12 | 303.260 | 2.014 | -0.020 | 11 | 309.679 | 0.815 | -0.140 | 6 | -1.20 |
| CB02 | 8 | 22 | 303.150 | 2.014 | 0.300 | 21 | 313.624 | 0.966 | -0.134 | 10 | -1.05 |
| CB02 | 8 | 32 | 288.540 | 1.921 | 0.230 | 30 | 302.390 | 0.780 | 0.316 | 14 | -1.14 |
| CB02 | 8 | 42 | 281.520 | 1.654 | 0.130 | 40 | 297.772 | 1.172 | 0.220 | 16 | -0.48 |
| CB02 | 8 | 52 | 277.470 | 1.547 | 0.110 | 49 | 290.043 | 1.094 | 0.049 | 13 | -0.45 |
| CB02 | 8 | 57 | 262.780 | 1.147 | 0.150 | 54 | 277.860 | 0.732 | 0.167 | 15 | -0.41 |
| CB02 | 9 | 4 | 340.190 | 1.151 | 0.060 | 5 | 307.192 | 1.148 | -0.286 | -33 | -0.01 |
| CB02 | 9 | 12 | 346.750 | 1.961 | 0.070 | 14 | 306.592 | 1.237 | -0.118 | -40 | -0.73 |
| CB02 | 9 | 22 | 350.140 | 1.885 | -0.060 | 25 | 305.142 | 1.288 | 0.097 | -45 | -0.60 |
| CB02 | 9 | 30 | 316.500 | 0.873 | -0.070 | 33 | 299.353 | 1.020 | 0.036 | -17 | 0.15 |
| CB02 | 10 | 12 | 335.430 | 1.948 | 0.050 | 11 | 306.842 | 1.110 | -0.269 | -29 | -0.83 |
| CB02 | 10 | 22 | 315.370 | 1.695 | 0.080 | 20 | 295.128 | 1.169 | -0.187 | -20 | -0.53 |
| CB02 | 10 | 27 | 303.990 | 1.227 | 0.060 | 24 | 280.963 | 0.917 | -0.082 | -23 | -0.31 |
| CB03 | 1 | 3 | 339.760 | 1.547 | -0.340 | 4 | 336.639 | 1.557 | -0.446 | -3 | 0.01 |
| CB03 | 1 | 12 | 322.930 | 1.662 | -0.400 | 10 | 333.575 | 1.460 | -0.475 | 11 | -0.20 |
| CB03 | 1 | 22 | 323.250 | 1.652 | -0.340 | 19 | 336.048 | 1.375 | -0.541 | 13 | -0.28 |
| CB03 | 1 | 39 | 254.440 | 1.289 | -0.010 | 34 | 337.039 | 1.099 | -0.235 | 83 | -0.19 |
| CB03 | 2 | 3 | 4.650 | 1.643 | -0.020 | 4 | 353.902 | 1.850 | 0.087 | -11 | 0.21 |
| CB03 | 2 | 12 | 335.940 | 1.566 | -0.020 | 10 | 346.724 | 1.797 | 0.036 | 11 | 0.23 |
| CB03 | 2 | 22 | 348.460 | 1.595 | -0.050 | 19 | 344.223 | 1.558 | -0.020 | -4 | -0.04 |
| CB03 | 2 | 32 | 337.800 | 1.786 | -0.130 | 28 | 349.933 | 1.380 | 0.058 | 12 | -0.40 |
| CB03 | 2 | 42 | 329.560 | 1.604 | 0.360 | 36 | 346.306 | 1.472 | 0.089 | 17 | -0.13 |
| CB03 | 2 | 52 | 258.090 | 1.108 | 0.250 | 45 | 317.661 | 1.019 | 0.130 | 59 | -0.09 |
| CB03 | 3 | 4 | 351.630 | 0.879 | -0.110 | 4 | 348.534 | 0.978 | -0.284 | -3 | 0.10 |
| CB03 | 3 | 12 | 327.650 | 1.165 | -0.040 | 9 | 350.938 | 1.161 | -0.187 | 23 | 0.00 |
| CB03 | 3 | 22 | 323.850 | 1.241 | 0.020 | 17 | 359.165 | 0.958 | 0.012 | 36 | -0.29 |
| CB03 | 3 | 22 | 323.850 | 1.241 | 0.020 | 25 | 354.843 | 1.002 | 0.099 | 31 | -0.24 |
| CB03 | 3 | 32 | 324.370 | 1.337 | 0.280 | 33 | 352.975 | 1.104 | 0.210 | 28 | -0.23 |
| CB03 | 3 | 42 | 299.870 | 1.394 | 0.490 | 41 | 353.909 | 1.078 | 0.200 | 54 | -0.32 |
| CB03 | 3 | 52 | 287.450 | 1.327 | 0.250 | 49 | 339.921 | 1.514 | 0.211 | 52 | 0.19 |
| CB03 | 3 | 52 | 287.450 | 1.327 | 0.250 | 57 | 339.621 | 1.608 | 0.158 | 52 | 0.28 |
| CB03 | 3 | 62 | 290.120 | 1.356 | 0.000 | 64 | 327.969 | 1.397 | 0.281 | 37 | 0.04 |
| CB03 | 4 | 12 | 320.440 | 1.337 | -0.180 | 12 | 356.239 | 0.964 | -0.321 | 36 | -0.37 |
| CB03 | 4 | 22 | 339.240 | 1.261 | -0.120 | 22 | 4.329 | 1.015 | -0.001 | 25 | -0.25 |
| CB03 | 4 | 32 | 328.810 | 1.347 | 0.270 | 32 | 0.523 | 1.130 | 0.306 | 32 | -0.21 |
| CB03 | 4 | 42 | 310.150 | 1.337 | 0.610 | 41 | 351.406 | 1.087 | 0.423 | 41 | -0.25 |
| CB03 | 4 | 52 | 315.580 | 1.241 | 0.360 | 51 | 346.481 | 1.147 | 0.154 | 31 | -0.10 |
| CB03 | 4 | 62 | 311.860 | 1.222 | 0.150 | 61 | 341.410 | 1.367 | 0.002 | 30 | 0.14 |
| CB03 | 5 | 22 | 323.210 | 1.146 | -0.200 | 21 | 5.113 | 1.017 | -0.023 | 42 | -0.13 |
| CB03 | 5 | 32 | 335.080 | 1.347 | 0.320 | 30 | 356.484 | 0.987 | 0.236 | 21 | -0.36 |
| CB03 | 6 | 3 | 321.210 | 0.774 | -0.340 | 4 | 352.499 | 0.755 | -0.446 | 31 | -0.02 |
| CB03 | 6 | 12 | 328.300 | 1.156 | -0.400 | 12 | 359.604 | 0.695 | -0.303 | 31 | -0.46 |
| CB03 | 6 | 22 | 340.550 | 1.308 | -0.140 | 23 | 2.898 | 0.844 | -0.184 | 22 | -0.46 |
| CB03 | 6 | 32 | 310.890 | 1.175 | 0.140 | 33 | 341.245 | 0.494 | -0.092 | 31 | -0.68 |
| CB03 | 6 | 37 | 308.680 | 0.879 | 0.090 | 38 | 330.164 | 0.197 | -0.040 | 22 | -0.68 |
| CB03 | 7 | 4 | 313.690 | 1.299 | -0.530 | 4 | 352.290 | 0.810 | -0.238 | 39 | -0.20 |
| CB03 | 7 | 12 | 324.620 | 1.003 | -0.230 | 11 | 344.673 | 0.804 | -0.168 | 20 | -0.20 |
| CB03 | 7 | 22 | 333.670 | 0.860 | -0.050 | 19 | 321.985 | 0.562 | -0.016 | -12 | -0.30 |

(Continued)

(Sheet 2 of 4)

Table 7 (Continued)

| Range | Station | Prototype Depth ft | Prototype Phase | Prototype Amplitude | Prototype Average | Model Depth. ft | Model Phase | Model Amplitude | Model Average | Model-Prototype Phase | Model-Prototype Amplitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CB03 | 8 | 4 | 305.830 | 0.774 | 0.110 | 4 | 327.173 | 0.837 | -0.135 | 22 | 0.06 |
| CB03 | 8 | 12 | 309.290 | 0.907 | 0.140 | 13 | 329.197 | 0.866 | -0.058 | 20 | -0.04 |
| CB03 | 8 | 18 | 305.120 | 0.563 | 0.030 | 19 | 327.585 | 0.755 | 0.020 | 26 | 0.19 |
| CB03 | 9 | 4 | 330.190 | 1.375 | -0.480 | 4 | 351.208 | 0.761 | -0.276 | 21 | -0.61 |
| CB03 | 9 | 12 | 332.360 | 1.232 | -0.270 | 11 | 349.263 | 0.753 | -0.157 | 17 | -0.48 |
| CB03 | 9 | 22 | 337.440 | 1.366 | -0.140 | 21 | 340.936 | 0.804 | 0.050 | 3 | -0.56 |
| CB03 | 9 | 32 | 326.970 | 1.251 | 0.110 | 30 | 338.572 | 0.729 | 0.035 | 12 | -0.53 |
| CB03 | 9 | 42 | 320.730 | 1.127 | 0.260 | 40 | 344.115 | 0.850 | 0.093 | 24 | -0.27 |
| CB03 | 9 | 52 | 309.550 | 0.764 | 0.280 | 49 | 304.418 | 0.669 | 0.258 | -5 | -0.10 |
| CB03 | 10 | 3 | 307.860 | 1.128 | -0.060 | 4 | 345.756 | 0.936 | -0.303 | 38 | -0.19 |
| CB03 | 10 | 12 | 308.470 | 1.251 | -0.060 | 11 | 338.182 | 0.843 | -0.157 | 30 | -0.41 |
| CB03 | 10 | 22 | 312.580 | 1.194 | 0.050 | 20 | 334.711 | 0.861 | 0.029 | 22 | -0.33 |
| CB03 | 10 | 52 | 277.990 | 0.831 | 0.210 | 48 | 337.774 | 0.849 | 0.255 | 60 | 0.01 |
| CB03 | 10 | 57 | 267.420 | 0.697 | 0.200 | 53 | 315.112 | 0.752 | 0.306 | 48 | 0.06 |
| CB03 | 11 | 15 | 276.180 | 1.060 | 0.050 | 14 | 310.762 | 0.780 | 0.036 | 34 | -0.28 |
| CB04 | 1 | 4 | 35.820 | 1.385 | -0.200 | 4 | 346.989 | 0.848 | -0.240 | -49 | -0.54 |
| CB04 | 1 | 12 | 31.820 | 1.625 | -0.230 | 12 | 58.363 | 1.260 | -0.316 | 27 | -0.36 |
| CB04 | 1 | 22 | 31.460 | 1.625 | -0.200 | 22 | 53.097 | 1.129 | -0.214 | 22 | -0.50 |
| CB04 | 1 | 32 | 25.450 | 1.597 | -0.240 | 32 | 42.164 | 0.892 | 0.032 | 17 | -0.70 |
| CB04 | 2 | 4 | 55.350 | 1.187 | -0.250 | 4 | 43.890 | 1.052 | -0.512 | -12 | -0.13 |
| CB04 | 2 | 12 | 64.800 | 1.356 | -0.290 | 12 | 67.800 | 1.072 | -0.354 | 3 | -0.13 |
| CB04 | 2 | 22 | 64.650 | 1.300 | -0.220 | 22 | 66.761 | 0.985 | 0.080 | 2 | -0.32 |
| CB04 | 2 | 32 | 63.720 | 1.342 | -0.090 | 31 | 65.937 | 0.904 | -0.024 | 2 | -0.44 |
| CB04 | 2 | 42 | 54.270 | 1.568 | -0.020 | 41 | 60.016 | 0.993 | 0.086 | 6 | -0.57 |
| CB04 | 3 | 12 | 62.180 | 1.272 | -0.330 | 12 | 71.459 | 1.053 | -0.389 | 9 | -0.22 |
| CB04 | 3 | 22 | 52.490 | 1.300 | -0.250 | 18 | 63.626 | 0.558 | 0.220 | 11 | -0.75 |
| CB04 | 3 | 22 | 52.490 | 1.300 | -0.250 | 22 | 74.486 | 1.120 | -0.101 | 22 | -0.18 |
| CB04 | 3 | 32 | 50.680 | 1.371 | -0.020 | 33 | 65.448 | 1.032 | 0.063 | 15 | -0.34 |
| CB04 | 3 | 52 | 47.150 | 1.455 | 0.300 | 53 | 57.772 | 0.934 | 0.161 | 10 | -0.52 |
| CB04 | 3 | 52 | 47.150 | 1.455 | 0.300 | 57 | 70.449 | 0.810 | -0.443 | 23 | -0.64 |
| CB04 | 3 | 62 | 49.490 | 1.102 | 0.110 | 61 | 30.272 | 0.258 | -0.032 | -19 | -0.85 |
| CB04 | 4 | 12 | 51.750 | 1.625 | 0.340 | 13 | 70.011 | 0.923 | -0.404 | 19 | -0.70 |
| CB04 | 4 | 22 | 57.140 | 1.272 | -0.218 | 24 | 75.364 | 0.916 | -0.240 | 18 | -0.36 |
| CB04 | 4 | 32 | 52.630 | 1.286 | -0.050 | 34 | 71.011 | 0.899 | 0.103 | 19 | -0.39 |
| CB04 | 4 | 42 | 44.170 | 1.342 | 0.110 | 45 | 72.578 | 0.733 | 0.255 | 28 | -0.61 |
| CB04 | 4 | 62 | 56.110 | 1.498 | 0.260 | 67 | 62.509 | 1.101 | 0.098 | 6 | -0.39 |
| CB04 | 4 | 72 | 46.900 | 1.554 | 0.230 | 77 | 59.446 | 1.104 | 0.132 | 13 | -0.45 |
| CB04 | 4 | 82 | 36.200 | 1.455 | 0.130 | 88 | 51.549 | 1.162 | 0.163 | 15 | -0.29 |
| CB04 | 4 | 92 | 43.150 | 1.356 | 0.130 | 99 | 42.840 | 0.874 | 0.116 | -1 | -0.48 |
| CB04 | 5 | 4 | 66.720 | 0.848 | -0.300 | 4 | 67.130 | 0.640 | -0.363 | 1 | -0.20 |
| CB04 | 5 | 12 | 47.650 | 1.031 | -0.290 | 12 | 65.864 | 0.935 | -0.328 | 18 | -0.10 |
| CB04 | 5 | 22 | 40.880 | 1.159 | -0.110 | 22 | 65.014 | 0.675 | -0.066 | 25 | -0.48 |
| CB04 | 5 | 42 | 49.350 | 1.130 | 0.340 | 42 | 61.084 | 0.802 | 0.145 | 12 | -0.33 |
| CB04 | 5 | 42 | 49.350 | 1.130 | 0.340 | 42 | 61.084 | 0.802 | 0.145 | 12 | -0.33 |
| CB04 | 5 | 52 | 51.280 | 1.229 | 0.420 | 52 | 67.260 | 0.946 | 0.167 | 16 | -0.28 |
| CB04 | 5 | 72 | 42.780 | 1.286 | 0.320 | 72 | 50.139 | 0.811 | 0.158 | 8 | -0.47 |
| CB04 | 5 | 82 | 33.690 | 0.904 | 0.210 | 82 | 52.184 | 1.110 | 0.099 | 19 | 0.21 |
| CB04 | 5 | 92 | 30.510 | 1.074 | 0.250 | 92 | 43.129 | 0.964 | 0.159 | 13 | -0.11 |
| CB04 | 5 | 97 | 36.270 | 1.243 | 0.270 | 97 | 32.880 | 0.851 | 0.102 | -4 | -0.39 |
| CB04 | 6 | 4 | 67.530 | 0.791 | -0.270 | 4 | 64.703 | 0.709 | -0.248 | -3 | -0.09 |
| CB04 | 6 | 12 | 43.210 | 1.130 | -0.370 | 13 | 61.246 | 0.647 | -0.031 | 18 | -0.49 |
| CB04 | 6 | 12 | 43.210 | 1.130 | -0.370 | 22 | 65.682 | 0.657 | 0.022 | 22 | -0.48 |
| CB04 | 7 | 4 | 35.920 | 0.777 | -0.090 | 4 | 62.331 | 0.784 | -0.201 | 27 | 0.01 |
| CB04 | 7 | 12 | 20.580 | 1.215 | -0.090 | 12 | 55.518 | 0.841 | -0.171 | 35 | -0.37 |
| CB04 | 7 | 16 | 31.420 | 0.466 | -0.030 | 14 | 54.901 | 0.591 | -0.110 | 23 | 0.13 |
| CB05 | 1 | 12 | 105.760 | 1.209 | -0.110 | 12 | 121.359 | 0.766 | -0.160 | 16 | -0.44 |
| CB05 | 1 | 22 | 105.070 | 0.990 | -0.030 | 22 | 106.241 | 0.794 | 0.023 | 1 | -0.20 |
| CB05 | 1 | 27 | 64.090 | 0.762 | -0.040 | 25 | 107.202 | 0.591 | -0.015 | 43 | -0.17 |
| CB05 | 2 | 12 | 84.990 | 1.130 | 0.020 | 12 | 132.750 | 0.652 | -0.207 | 48 | -0.48 |
| CB05 | 2 | 22 | 92.870 | 1.113 | -0.050 | 23 | 122.381 | 0.735 | -0.059 | 30 | -0.38 |
| CB05 | 2 | 32 | 92.580 | 0.867 | -0.030 | 33 | 117.929 | 0.626 | -0.094 | 25 | -0.24 |
| CB05 | 3 | 12 | 108.860 | 1.296 | 0.020 | 12 | 139.474 | 0.725 | -0.263 | 31 | -0.57 |
| CB05 | 3 | 42 | 110.690 | 0.929 | 0.200 | 22 | 135.345 | 0.696 | -0.065 | 25 | -0.23 |
| CB05 | 3 | 42 | 110.690 | 0.929 | 0.200 | 42 | 96.463 | 0.924 | 0.101 | -14 | 0.00 |
| CB05 | 4 | 12 | 142.750 | 1.076 | -0.080 | 4 | 142.356 | 0.760 | -0.341 | 0 | -0.31 |

(Continued)

Table 7 (Concluded)

| | | Prototype | | | | Model | | | | Model-Prototype | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range | Station | Depth ft | Phase | Amplitude | Average | Depth ft | Phase | Amplitude | Average | Phase | Amplitude |
| CB05 | 4 | 12 | 142.750 | 1.076 | -0.080 | 12 | 136.665 | 0.728 | -0.240 | -6 | -0.35 |
| CB05 | 4 | 22 | 158.510 | 0.915 | 0.020 | 22 | 136.621 | 0.944 | 0.018 | -22 | 0.03 |
| CB05 | 4 | 32 | 148.450 | 0.841 | 0.110 | 32 | 133.027 | 0.756 | 0.036 | -15 | -0.09 |
| CB05 | 4 | 42 | 161.690 | 1.089 | 0.180 | 42 | 130.245 | 0.905 | 0.097 | -31 | -0.18 |
| CB05 | 4 | 62 | 125.420 | 0.594 | 0.130 | 61 | 120.720 | 0.697 | 0.147 | -5 | -0.10 |
| CB05 | 5 | 22 | 116.790 | 1.130 | 0.030 | 21 | 140.610 | 1.002 | -0.027 | 24 | -0.13 |
| CB05 | 5 | 42 | 116.950 | 1.042 | -0.010 | 40 | 132.034 | 1.105 | 0.024 | 16 | 0.06 |
| CB05 | 5 | 52 | 111.440 | 1.016 | 0.040 | 49 | 123.881 | 1.094 | 0.140 | 12 | 0.08 |
| CB05 | 5 | 62 | 111.170 | 0.920 | 0.100 | 59 | 130.712 | 0.905 | 0.270 | 19 | -0.02 |
| CB05 | 5 | 72 | 109.580 | 0.920 | 0.130 | 68 | 125.555 | 0.711 | 0.216 | 16 | -0.21 |
| CB05 | 5 | 72 | 109.580 | 0.920 | 0.130 | 78 | 111.941 | 0.698 | 0.276 | 2 | -0.23 |
| CB05 | 5 | 82 | 110.880 | 0.990 | 0.180 | 87 | 121.954 | 0.625 | 0.176 | 11 | -0.37 |
| CB05 | 5 | 92 | 92.410 | 0.526 | 0.110 | 97 | 94.646 | 0.687 | 0.275 | 2 | 0.16 |
| CB05 | 6 | 22 | 89.920 | 0.815 | -0.120 | 21 | 128.415 | 0.588 | -0.186 | 39 | -0.23 |
| CB06 | 1 | 2 | 185.580 | 0.910 | 0.080 | 4 | 161.698 | 0.768 | -0.112 | -24 | -0.15 |
| CB06 | 1 | 12 | 180.490 | 1.130 | -0.010 | 12 | 139.354 | 0.386 | 0.066 | -41 | -0.75 |
| CB06 | 1 | 20 | 178.360 | 0.670 | 0.040 | 18 | 135.555 | 0.294 | 0.013 | -43 | -0.38 |
| CB06 | 2 | 2 | 193.900 | 0.990 | 0.070 | 4 | 170.340 | 0.792 | -0.323 | -23 | -0.20 |
| CB06 | 2 | 12 | 185.850 | 1.200 | -0.030 | 12 | 154.741 | 0.771 | -0.023 | -31 | -0.43 |
| CB06 | 2 | 18 | 178.040 | 0.970 | -0.020 | 16 | 132.269 | 0.634 | 0.138 | -46 | -0.34 |
| CB06 | 3 | 2 | 195.410 | 1.060 | -0.020 | 4 | 163.929 | 0.959 | -0.176 | -32 | -0.11 |
| CB06 | 3 | 32 | 167.480 | 0.700 | 0.040 | 29 | 154.764 | 0.392 | -0.060 | -13 | -0.31 |
| CB06 | 4 | 2 | 191.300 | 1.190 | 0.000 | 4 | 171.092 | 0.755 | -0.316 | -20 | -0.44 |
| CB06 | 4 | 22 | 195.370 | 1.340 | 0.050 | 21 | 159.666 | 0.969 | 0.134 | -36 | -0.38 |
| CB06 | 4 | 32 | 171.530 | 0.990 | -0.030 | 30 | 141.965 | 0.746 | 0.336 | -20 | -0.25 |
| CB06 | 5 | 2 | 174.820 | 1.340 | 0.070 | 4 | 175.697 | 0.876 | -0.369 | 1 | -0.47 |
| CB06 | 5 | 12 | 179.800 | 1.550 | 0.010 | 11 | 161.212 | 0.878 | -0.015 | -18 | -0.68 |
| CB06 | 5 | 12 | 179.800 | 1.550 | 0.010 | 16 | 149.909 | 0.397 | 0.105 | -30 | -1.16 |
| CB07 | 1 | 4 | 172.420 | 1.530 | 0.010 | 4 | 196.714 | 1.535 | -0.249 | 24 | 0.00 |
| CB07 | 1 | 11 | 165.190 | 1.070 | 0.090 | 11 | 192.202 | 0.901 | -0.106 | -27 | -0.17 |
| CB07 | 2 | 2 | 188.590 | 1.851 | -0.460 | 4 | 197.223 | 1.914 | -0.240 | 9 | 0.06 |
| CB07 | 2 | 13 | 188.220 | 1.782 | -0.290 | 11 | 192.366 | 1.431 | -0.226 | 4 | -0.35 |
| CB07 | 3 | 2 | 201.220 | 2.269 | -0.300 | 4 | 194.459 | 2.215 | -0.400 | -7 | -0.05 |
| CB07 | 3 | 4 | 224.910 | 2.277 | -0.510 | 5 | 199.694 | 2.116 | -0.510 | -25 | -0.16 |
| CB07 | 3 | 12 | 200.600 | 2.230 | -0.200 | 14 | 190.928 | 1.892 | -0.206 | -10 | -0.34 |
| CB07 | 3 | 22 | 196.290 | 1.800 | -0.060 | 25 | 180.049 | 1.521 | -0.034 | -16 | -0.28 |
| CB07 | 3 | 28 | 189.130 | 1.330 | 0.010 | 30 | 170.207 | 0.994 | -0.078 | -19 | -0.34 |
| CB07 | 4 | 2 | 186.130 | 1.997 | 0.180 | 4 | 187.426 | 1.826 | -0.203 | 1 | -0.17 |
| CB07 | 4 | 12 | 180.910 | 1.967 | 0.230 | 12 | 184.781 | 1.645 | -0.085 | 4 | -0.32 |
| CB07 | 4 | 22 | 184.760 | 1.500 | 0.160 | 20 | 175.127 | 1.345 | -0.017 | -9 | -0.16 |
| CB07 | 5 | 2 | 157.220 | 1.627 | -0.010 | 4 | 189.627 | 0.907 | -0.135 | 32 | -0.72 |
| CB07 | 5 | 12 | 161.280 | 1.539 | -0.020 | 16 | 173.905 | 1.070 | -0.223 | 12 | -0.46 |
| CB07 | 5 | 22 | 164.790 | 1.364 | 0.000 | 29 | 173.375 | 1.479 | 0.204 | 9 | 0.11 |
| CB07 | 5 | 32 | 161.760 | 1.334 | 0.060 | 42 | 184.208 | 0.913 | 0.431 | 23 | -0.42 |

(Sheet 4 of 4)

Table 8

Velocity Verification Test No. 22, 11 July 1978

| | | Prototype | | | | Model | | | | Model-Prototype | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range | Station | Depth ft | Phase | Amplitude | Average | Depth ft | Phase | Amplitude | Average | Phase | Amplitude |
| J01 | 1 | 3 | 141.340 | 1.432 | 0.000 | 4 | 182.253 | 1.702 | -0.164 | 41 | 0.27 |
| J01 | 1 | 13 | 158.130 | 0.931 | 0.010 | 12 | 176.339 | 1.453 | -0.022 | 18 | 0.52 |
| J01 | 2 | 2 | 207.180 | 2.204 | -0.600 | 4 | 209.854 | 2.891 | -0.638 | 2 | 0.69 |
| J01 | 2 | 12 | 226.880 | 2.803 | -0.680 | 12 | 208.415 | 2.663 | -0.566 | -18 | -0.14 |
| J01 | 2 | 22 | 220.350 | 2.375 | -0.380 | 22 | 201.990 | 2.474 | -0.532 | -19 | 0.10 |
| J01 | 2 | 42 | 217.910 | 2.584 | -0.570 | 36 | 203.411 | 2.453 | -0.514 | -14 | -0.13 |
| J01 | 2 | 42 | 217.910 | 2.584 | -0.570 | 46 | 207.563 | 2.253 | -0.216 | -10 | -0.33 |
| J01 | 3 | 6 | 96.830 | 2.318 | -0.320 | 4 | 210.822 | 1.925 | -0.342 | 114 | -0.40 |
| J01 | 3 | 16 | 191.110 | 2.595 | -0.180 | 16 | 210.761 | 1.990 | -0.138 | 19 | -0.61 |
| J01 | 3 | 36 | 191.970 | 1.897 | 0.320 | 34 | 204.699 | 2.052 | 0.028 | 13 | 0.15 |
| J01 | 3 | 56 | 178.420 | 1.495 | 1.040 | 53 | 207.901 | 2.303 | -0.123 | 29 | 0.80 |
| J01 | 3 | 56 | 178.420 | 1.495 | 1.040 | 62 | 208.081 | 2.122 | -0.068 | 30 | 0.62 |
| J01 | 3 | 66 | 149.110 | 1.325 | 1.340 | 72 | 209.211 | 2.592 | -0.401 | 60 | 1.27 |
| J01 | 3 | 76 | 133.590 | 0.797 | 1.160 | 77 | 206.633 | 2.176 | -0.326 | 73 | 1.38 |
| J02 | 1 | 7 | 224.510 | 1.473 | -0.160 | 4 | 231.213 | 2.055 | -0.310 | 7 | 0.59 |
| J02 | 1 | 7 | 224.510 | 1.473 | -0.160 | 9 | 226.314 | 1.828 | -0.170 | 2 | 0.36 |
| J02 | 2 | 2 | 259.850 | 2.196 | -0.830 | 4 | 242.674 | 2.591 | -0.624 | -17 | 0.39 |
| J02 | 2 | 12 | 245.580 | 1.647 | 0.280 | 12 | 238.122 | 2.267 | -0.282 | -7 | 0.62 |
| J02 | 2 | 12 | 245.580 | 1.647 | -0.280 | 22 | 218.630 | 1.687 | 0.002 | -27 | 0.04 |
| J02 | 3 | 5 | 247.010 | 1.894 | -0.230 | 5 | 240.569 | 2.161 | -0.519 | -7 | 0.27 |
| J02 | 3 | 15 | 246.640 | 1.748 | -0.020 | 15 | 241.815 | 2.275 | 0.137 | -5 | 0.53 |
| J02 | 3 | 25 | 250.050 | 1.793 | 0.000 | 25 | 232.969 | 2.315 | 0.127 | -18 | 0.53 |
| J02 | 3 | 35 | 245.590 | 1.537 | 0.020 | 35 | 225.285 | 2.214 | 0.334 | -20 | 0.67 |
| J02 | 3 | 45 | 233.730 | 1.295 | 0.280 | 45 | 221.856 | 1.656 | 0.332 | -12 | 0.36 |
| J03 | 1 | 3 | 274.030 | 1.473 | 0.030 | 4 | 251.272 | 1.894 | -0.085 | -23 | 0.41 |
| J03 | 1 | 12 | 263.230 | 1.391 | 0.030 | 11 | 257.693 | 1.569 | 0.055 | -6 | 0.18 |
| J03 | 1 | 20 | 282.430 | 0.988 | 0.080 | 16 | 255.937 | 1.254 | 0.059 | -27 | 0.26 |
| J03 | 2 | 2 | 273.760 | 1.912 | -0.330 | 4 | 258.104 | 2.170 | -0.236 | -15 | 0.26 |
| J03 | 2 | 7 | 276.590 | 1.656 | -0.250 | 13 | 259.565 | 1.690 | -0.254 | -17 | 0.23 |
| J03 | 2 | 7 | 276.590 | 1.656 | -0.250 | 17 | 258.503 | 1.598 | -0.193 | -18 | -0.06 |
| J04 | 1 | 2 | 282.640 | 1.623 | -0.420 | 4 | 280.392 | 1.697 | 0.114 | -2 | 0.08 |
| J04 | 1 | 9 | 294.300 | 1.858 | 0.010 | 10 | 282.449 | 1.689 | 0.124 | -12 | -0.17 |
| J04 | 1 | 15 | 290.750 | 1.125 | -0.290 | 15 | 283.404 | 1.481 | 0.034 | -7 | 0.36 |
| J04 | 2 | 2 | 297.300 | 1.447 | -0.640 | 4 | 301.284 | 1.353 | -0.203 | 4 | -0.10 |
| J04 | 2 | 12 | 305.020 | 1.672 | -0.030 | 12 | 296.647 | 1.140 | -0.155 | -9 | -0.53 |
| J04 | 2 | 19 | 278.460 | 0.734 | -0.200 | 16 | 293.311 | 0.771 | -0.218 | 15 | 0.04 |
| J05 | 1 | 2 | 308.690 | 1.968 | 0.160 | 4 | 301.282 | 2.019 | -0.013 | -7 | 0.05 |
| J05 | 1 | 11 | 306.710 | 2.047 | 0.070 | 11 | 302.588 | 1.774 | 0.042 | -4 | -0.28 |
| J05 | 1 | 21 | 305.170 | 1.496 | 0.160 | 19 | 331.531 | 1.442 | 0.002 | 26 | -0.06 |
| J05 | 2 | 3 | 315.510 | 2.234 | -0.090 | 4 | 314.249 | 1.826 | 0.048 | -1 | -0.40 |
| J05 | 2 | 13 | 323.710 | 2.135 | -0.010 | 11 | 313.041 | 1.736 | -0.058 | -10 | -0.40 |
| J05 | 2 | 23 | 328.610 | 2.096 | 0.050 | 19 | 314.531 | 1.696 | -0.094 | -14 | -0.40 |
| J05 | 2 | 23 | 328.610 | 2.096 | 0.050 | 28 | 313.747 | 1.661 | -0.052 | -15 | -0.44 |
| J05 | 2 | 33 | 327.990 | 2.066 | 0.060 | 37 | 339.470 | 1.352 | 0.032 | 12 | -0.72 |
| J06 | 1 | 3 | 330.590 | 1.848 | -0.120 | 4 | 344.382 | 1.991 | -0.240 | 14 | 0.15 |
| J06 | 1 | 13 | 332.930 | 1.742 | -0.080 | 10 | 341.184 | 1.920 | -0.195 | 9 | 0.18 |
| J06 | 1 | 23 | 330.730 | 1.549 | -0.060 | 18 | 340.577 | 1.721 | -0.256 | 10 | 0.17 |
| J06 | 1 | 29 | 330.360 | 1.267 | -0.040 | 21 | 340.128 | 1.563 | -0.211 | 10 | 0.29 |
| J07 | 1 | 3 | 288.000 | 2.200 | -0.090 | 4 | 350.637 | 2.711 | -0.312 | 62 | 0.51 |
| J07 | 1 | 13 | 279.910 | 2.033 | -0.070 | 13 | 352.299 | 2.645 | -0.344 | 73 | 0.61 |
| J07 | 1 | 23 | 278.980 | 1.382 | 0.070 | 23 | 352.640 | 2.443 | 0.312 | 74 | 1.06 |
| J07 | 1 | 28 | 280.210 | 1.672 | -0.090 | 26 | 352.697 | 2.403 | -0.387 | 72 | 0.73 |
| J08 | 1 | 5 | 12.240 | 2.138 | -0.050 | 5 | 10.597 | 1.969 | -0.339 | -2 | -0.17 |
| J08 | 1 | 15 | 4.380 | 2.112 | -0.180 | 16 | 12.682 | 1.728 | -0.482 | 8 | -0.38 |
| J08 | 1 | 25 | 8.150 | 1.672 | -0.130 | 26 | 9.368 | 1.331 | -0.312 | 1 | -0.34 |
| | | | | | | York River | | | | | |
| Y01 | 1 | 13 | 247.320 | 1.318 | -0.360 | 4 | 222.740 | 0.996 | -0.240 | -25 | -0.32 |
| Y01 | 1 | 23 | 250.240 | 1.087 | -0.060 | 24 | 215.264 | 0.998 | 0.047 | -35 | -0.09 |
| Y01 | 1 | 33 | 228.690 | 0.962 | 0.110 | 33 | 195.977 | 0.837 | 0.050 | -33 | -0.13 |
| Y01 | 2 | 15 | 219.530 | 1.203 | 0.010 | 15 | 216.686 | 0.952 | -0.070 | -3 | -0.25 |
| Y01 | 2 | 35 | 214.430 | 1.039 | 0.270 | 36 | 197.135 | 0.944 | 0.022 | -17 | -0.10 |
| Y01 | 2 | 45 | 212.920 | 1.029 | 0.310 | 46 | 178.656 | 0.786 | 0.065 | -34 | -0.24 |
| Y01 | 2 | 53 | 232.640 | 0.750 | 0.220 | 52 | 170.133 | 0.662 | 0.133 | -62 | -0.09 |
| Y02 | 1 | 4 | 258.070 | 1.690 | -0.910 | 4 | 236.045 | 1.588 | -0.458 | -22 | -0.10 |

(Continued)

(Sheet 1 of 7)

Table 8 (Continued)

| Range | Station | Prototype Depth ft | Prototype Phase | Prototype Amplitude | Prototype Average | Model Depth ft | Model Phase | Model Amplitude | Model Average | Model-Prototype Phase | Model-Prototype Amplitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | York River (Continued) | | | | | | |
| Y02 | 1 | 14 | 265.300 | 1.709 | -0.420 | 14 | 226.359 | 1.560 | -0.143 | -39 | -0.15 |
| Y02 | 1 | 24 | 270.560 | 1.622 | -0.050 | 24 | 222.352 | 1.483 | -0.031 | -48 | -0.14 |
| Y02 | 1 | 52 | 246.280 | 1.248 | 0.400 | 52 | 208.169 | 1.362 | 0.102 | -38 | +0.11 |
| Y02 | 1 | 70 | 231.410 | 0.902 | 0.520 | 68 | 207.799 | 1.193 | 0.098 | -24 | +0.29 |
| Y03 | 1 | 13 | 250.850 | 1.238 | 0.130 | 14 | 215.952 | 1.080 | 0.019 | -35 | -0.16 |
| Y03 | 2 | 3 | 271.780 | 2.035 | -0.960 | 6 | 239.180 | 1.637 | -0.587 | -32 | -0.40 |
| Y03 | 2 | 13 | 274.130 | 1.978 | -0.380 | 11 | 232.365 | 1.463 | -0.340 | -42 | -0.52 |
| Y03 | 2 | 23 | 249.610 | 1.526 | 0.010 | 20 | 224.666 | 1.445 | -0.017 | -25 | -0.08 |
| Y03 | 2 | 23 | 249.610 | 1.526 | 0.010 | 26 | 216.615 | 1.146 | 0.016 | -33 | -0.38 |
| Y04 | 2 | 13 | 286.300 | 2.208 | -0.190 | 14 | 236.704 | 1.417 | -0.006 | -50 | -0.79 |
| Y04 | 2 | 23 | 228.320 | 1.901 | 0.410 | 25 | 231.806 | 1.367 | 0.092 | -47 | -0.61 |
| Y04 | 2 | 33 | 253.970 | 1.184 | 0.440 | 31 | 225.435 | 1.002 | 0.199 | -28 | -0.10 |
| Y05 | 1 | 4 | 275.060 | 2.748 | -0.330 | 4 | 254.508 | 2.530 | -0.427 | -21 | -0.22 |
| Y05 | 1 | 14 | 219.670 | 1.394 | 0.110 | 15 | 247.545 | 2.141 | 0.072 | +28 | +0.75 |
| Y05 | 1 | 23 | 258.090 | 2.139 | 0.280 | 25 | 238.036 | 1.673 | 0.226 | -20 | -0.47 |
| Y06 | 1 | 14 | 287.180 | 2.526 | -0.070 | 15 | 269.572 | 2.032 | -0.253 | -18 | -0.49 |
| Y06 | 1 | 24 | 286.090 | 2.023 | 0.150 | 24 | 261.761 | 1.584 | 0.198 | -25 | -0.44 |
| Y07 | 1 | 12 | 305.540 | 1.588 | -0.080 | 11 | 277.441 | 2.485 | -0.161 | -28 | +0.89 |
| Y07 | 1 | 17 | 308.020 | 2.052 | -0.130 | 14 | 280.539 | 2.130 | -0.081 | -28 | +0.08 |
| Y07 | 2 | 14 | 250.940 | 0.832 | -0.100 | 10 | 271.409 | 3.647 | -0.520 | +21 | +2.81 |
| | | | | | Rappahannock River | | | | | | |
| R01 | 2 | 2 | 295.550 | 1.342 | 0.300 | 4 | 274.140 | 0.682 | -0.032 | -21 | -0.66 |
| R01 | 2 | 12 | 302.090 | 1.386 | 0.200 | 12 | 277.549 | 0.759 | 0.060 | -25 | -0.63 |
| R01 | 2 | 22 | 311.440 | 1.221 | 0.100 | 23 | 260.528 | 0.689 | 0.143 | -51 | -0.53 |
| R01 | 2 | 32 | 301.110 | 0.737 | 0.010 | 32 | 244.097 | 0.376 | 0.108 | -57 | -0.36 |
| R04 | 1 | 2 | 320.910 | 1.221 | -0.160 | 4 | 299.820 | 0.975 | -0.177 | -21 | -0.25 |
| R04 | 1 | 12 | 328.850 | 1.166 | -0.130 | 13 | 289.581 | 0.865 | 0.125 | -39 | -0.30 |
| R04 | 1 | 20 | 306.060 | 0.814 | -0.030 | 20 | 269.185 | 0.540 | 0.081 | -37 | -0.27 |
| R02 | 2 | 2 | 316.750 | 1.084 | -0.280 | 4 | 298.042 | 0.762 | -0.232 | -19 | -0.32 |
| R02 | 2 | 22 | 313.890 | 1.023 | -0.090 | 22 | 300.706 | 0.623 | -0.038 | -13 | -0.40 |
| R02 | 2 | 42 | 304.700 | 0.935 | 0.320 | 43 | 296.370 | 0.639 | 0.009 | -8 | -0.30 |
| R02 | 2 | 52 | 294.810 | 0.795 | 0.270 | 53 | 298.932 | 0.553 | 0.033 | +4 | -0.24 |
| R06 | 1 | 2 | 1.900 | 1.837 | -0.080 | 4 | 310.981 | 1.131 | -0.143 | -47 | -0.71 |
| R06 | 1 | 12 | 349.520 | 1.375 | 0.100 | 13 | 305.654 | 1.105 | -0.022 | -56 | -0.27 |
| R06 | 1 | 16 | 333.280 | 0.968 | 0.200 | 15 | 306.877 | 1.041 | 0.003 | -54 | +0.07 |
| R08 | 1 | 2 | 18.100 | 2.174 | -0.230 | 4 | 350.058 | 1.813 | -0.469 | -12 | -0.36 |
| R08 | 1 | 12 | 5.270 | 2.199 | -0.020 | 11 | 348.808 | 1.696 | -0.310 | -13 | -0.50 |
| R08 | 1 | 22 | 9.970 | 1.558 | 0.200 | 20 | 351.098 | 1.192 | -0.072 | -10 | -0.37 |
| R10 | 1 | 2 | 55.470 | 2.368 | -0.190 | 4 | 27.555 | 0.969 | 0.024 | +25 | -1.40 |
| R10 | 1 | 12 | 57.060 | 2.090 | 0.020 | 12 | 26.458 | 0.697 | -0.119 | +24 | -1.39 |
| | | | | | Potomac River | | | | | | |
| P001 | 1 | 2 | 350.910 | 0.874 | -0.440 | 4 | 335.959 | 0.730 | -0.073 | -15 | -0.14 |
| P001 | 1 | 12 | 350.280 | 1.781 | -0.330 | 11 | 338.745 | 0.615 | -0.101 | -11 | -1.20 |
| P001 | 1 | 22 | 337.630 | 1.338 | -0.060 | 20 | 325.948 | 0.384 | 0.042 | -12 | -0.95 |
| P001 | 1 | 29 | 330.080 | 0.630 | -0.030 | 24 | 336.953 | 0.241 | 0.012 | 7 | -0.39 |
| P001 | 2 | 2 | 357.050 | 0.951 | -0.700 | 4 | 344.250 | 0.856 | -0.274 | -13 | -0.09 |
| P001 | 2 | 12 | 0.000 | 1.128 | -0.560 | 12 | 351.188 | 0.803 | -0.176 | -9 | -0.33 |
| P001 | 2 | 22 | 351.710 | 1.316 | -0.130 | 23 | 349.009 | 0.697 | -0.083 | -3 | -0.62 |
| P001 | 2 | 37 | 333.760 | 0.553 | 0.180 | 36 | 336.798 | 0.490 | -0.023 | 3 | -0.06 |
| P001 | 3 | 2 | 344.150 | 1.006 | -0.420 | 4 | 341.925 | 0.628 | -0.193 | -2 | -0.38 |
| P001 | 3 | 12 | 350.990 | 1.305 | -0.250 | 12 | 342.654 | 0.583 | -0.034 | -8 | -0.72 |
| P001 | 3 | 22 | 353.470 | 1.294 | 0.080 | 22 | 341.509 | 0.541 | 0.042 | -12 | -0.75 |
| P001 | 3 | 32 | 346.340 | 1.040 | 0.240 | 32 | 335.564 | 0.563 | 0.042 | -11 | -0.48 |
| P001 | 3 | 40 | 335.900 | 0.608 | 0.240 | 38 | 323.003 | 0.302 | 0.082 | -13 | -0.31 |
| P001 | 4 | 2 | 8.660 | 0.874 | -0.140 | 4 | 345.812 | 0.469 | -0.125 | -23 | -0.41 |
| P001 | 4 | 12 | 3.760 | 1.150 | 0.130 | 12 | 338.165 | 0.679 | 0.124 | -26 | -0.47 |
| P001 | 4 | 22 | 4.890 | 0.896 | 0.310 | 22 | 339.549 | 0.646 | 0.161 | -25 | -0.25 |
| P001 | 0 | 32 | 350.160 | 0.741 | 0.400 | 32 | 343.707 | 0.595 | 0.113 | -6 | -0.15 |
| P001 | 4 | 42 | 337.080 | 0.619 | 0.430 | 42 | 335.846 | 0.641 | 0.110 | -1 | 0.02 |
| P001 | 4 | 50 | 342.770 | 0.487 | 0.260 | 50 | 324.583 | 0.382 | 0.085 | -18 | -0.11 |
| P001 | 5 | 2 | 346.640 | 0.586 | -0.350 | 4 | 330.725 | 0.869 | 0.089 | -16 | 0.28 |
| P001 | 5 | 12 | 327.510 | 0.841 | -0.340 | 12 | 322.619 | 0.807 | 0.041 | -5 | -0.03 |
| P001 | 5 | 22 | 326.000 | 0.841 | -0.150 | 21 | 315.000 | 0.707 | -0.005 | -11 | -0.13 |
| P001 | 5 | 31 | 303.810 | 0.332 | 0.030 | 28 | 316.036 | 0.381 | -0.053 | 12 | 0.05 |
| P002 | 1 | 2 | 352.700 | 0.602 | -0.290 | 4 | 354.796 | 0.535 | -0.095 | 2 | -0.07 |

(Continued)

Table 8 (Continued)

| | | Prototype | | | | Model | | | | Model-Prototype | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range | Station | Depth ft | Phase | Amplitude | Average | Depth ft | Phase | Amplitude | Average | Phase | Amplitude |
| | | | | | Potomac River (Continued) | | | | | | |
| P002 | 1 | 22 | 349.440 | 0.602 | -0.070 | 23 | 339.931 | 0.435 | -0.020 | -10 | -0.17 |
| P002 | 1 | 30 | 333.430 | 0.377 | -0.030 | 30 | 313.022 | 0.204 | -0.048 | -20 | -0.17 |
| P002 | 2 | 2 | 0.310 | 0.768 | -0.220 | 4 | 354.003 | 0.431 | -0.232 | -6 | -0.34 |
| P002 | 2 | 12 | 353.300 | 0.919 | -0.120 | 11 | 1.621 | 0.450 | -0.058 | 8 | -0.47 |
| P002 | 2 | 22 | 356.890 | 0.738 | 0.120 | 20 | 2.952 | 0.506 | 0.038 | 6 | -0.23 |
| P002 | 2 | 32 | 348.590 | 0.610 | 0.340 | 26 | 357.590 | 0.483 | 0.029 | 9 | -0.13 |
| P002 | 2 | 42 | 358.430 | 0.565 | 0.420 | 39 | 2.947 | 0.496 | -0.018 | 5 | -0.07 |
| P002 | 2 | 42 | 358.430 | 0.565 | 0.420 | 48 | 0.471 | 0.507 | -0.006 | 2 | -0.06 |
| P002 | 2 | 60 | 346.860 | 0.580 | 0.110 | 55 | 1.428 | 0.398 | -0.073 | 15 | -0.18 |
| P002 | 3 | 12 | 345.810 | 0.716 | -0.060 | 4 | 356.999 | 0.502 | -0.225 | 11 | -0.21 |
| P002 | 3 | 12 | 345.810 | 0.716 | -0.060 | 12 | 351.970 | 0.496 | -0.030 | 6 | -0.22 |
| P002 | 3 | 22 | 329.380 | 0.620 | 0.170 | 23 | 339.764 | 0.440 | -0.019 | 10 | -0.18 |
| P002 | 3 | 30 | 314.660 | 0.377 | 0.090 | 30 | 352.076 | 0.347 | -0.096 | 37 | -0.03 |
| P003 | 1 | 2 | 4.670 | 0.770 | -0.540 | 2 | 10.540 | 0.708 | -0.201 | 6 | -0.06 |
| P003 | 1 | 12 | 293.870 | 0.690 | -0.310 | 12 | 7.116 | 0.780 | -0.092 | 73 | 0.09 |
| P003 | 1 | 22 | 353.600 | 0.750 | 0.050 | 22 | 7.902 | 0.845 | 0.007 | 14 | 0.10 |
| P003 | 1 | 32 | 356.560 | 0.800 | 0.250 | 33 | 2.099 | 0.835 | 0.004 | 6 | 0.03 |
| P003 | 1 | 52 | 358.950 | 0.720 | 0.280 | 43 | 359.198 | 0.825 | -0.001 | 0 | 0.11 |
| P003 | 1 | 52 | 358.950 | 0.720 | 0.280 | 53 | 352.883 | 0.830 | 0.034 | -6 | 0.11 |
| P003 | 1 | 57 | 351.970 | 0.796 | 0.000 | 58 | 354.147 | 0.673 | 0.041 | 2 | -0.12 |
| P003 | 2 | 2 | 5.310 | 0.630 | -0.380 | 4 | 16.108 | 0.356 | -0.182 | 11 | -0.27 |
| P003 | 2 | 22 | 7.590 | 0.885 | 0.110 | 23 | 6.157 | 0.621 | 0.210 | -1 | -0.26 |
| P003 | 2 | 32 | 356.990 | 0.852 | 0.040 | 33 | 341.852 | 0.638 | 0.136 | -15 | -0.21 |
| P003 | 2 | 36 | 339.860 | 0.675 | 0.000 | 35 | 343.346 | 0.575 | 0.067 | 3 | -0.10 |
| P004 | 1 | 2 | 31.410 | 1.004 | -0.140 | 4 | 31.523 | 0.894 | -0.313 | 0 | -0.11 |
| P004 | 1 | 12 | 26.680 | 1.092 | -0.010 | 13 | 26.632 | 0.846 | -0.023 | 0 | -0.23 |
| P004 | 1 | 22 | 12.480 | 0.686 | 0.070 | 24 | 5.318 | 0.854 | 0.047 | -7 | 0.17 |
| P004 | 2 | 2 | 33.090 | 1.203 | -0.140 | 4 | 40.809 | 1.157 | -0.166 | 8 | -0.05 |
| P004 | 2 | 12 | 32.240 | 1.306 | 0.030 | 11 | 34.330 | 0.972 | 0.141 | 2 | -0.33 |
| P004 | 2 | 22 | 31.490 | 1.417 | 0.170 | 21 | 29.500 | 1.106 | 0.194 | -2 | -0.31 |
| P004 | 2 | 42 | 9.580 | 0.708 | 0.150 | 38 | 5.592 | 1.014 | -0.022 | -4 | 0.31 |
| P005 | 1 | 2 | 10.070 | 0.326 | -0.360 | 4 | 44.631 | 0.402 | -0.098 | 35 | 0.08 |
| P005 | 1 | 12 | 19.400 | 0.473 | -0.230 | 12 | 35.648 | 0.277 | -0.035 | 16 | -0.20 |
| P005 | 2 | 2 | 30.410 | 0.585 | -0.580 | 4 | 61.880 | 0.548 | -0.166 | 31 | -0.04 |
| P005 | 2 | 10 | 36.880 | 0.810 | -0.130 | 9 | 66.651 | 0.720 | -0.049 | 30 | -0.09 |
| P005 | 2 | 19 | 67.070 | 0.304 | -0.020 | 16 | 54.507 | 0.521 | 0.051 | -13 | 0.22 |
| P005 | 3 | 2 | 35.030 | 0.924 | -0.230 | 4 | 54.527 | 0.985 | -0.434 | 19 | 0.06 |
| P005 | 3 | 10 | 35.310 | 0.889 | 0.150 | 12 | 54.397 | 0.779 | -0.193 | 19 | -0.11 |
| P005 | 3 | 19 | 19.190 | 0.427 | 0.300 | 22 | 57.927 | 0.517 | 0.086 | 39 | 0.09 |
| P006 | 1 | 2 | 78.210 | 1.508 | -0.350 | 4 | 95.040 | 1.714 | -0.334 | 17 | 0.21 |
| P006 | 1 | 12 | 87.720 | 1.392 | -0.290 | 10 | 95.771 | 1.902 | -0.238 | 8 | 0.51 |
| P006 | 1 | 22 | 87.840 | 1.312 | -0.170 | 19 | 91.891 | 1.826 | -0.064 | 4 | 0.51 |
| P006 | 1 | 32 | 86.080 | 1.262 | -0.020 | 28 | 90.927 | 1.855 | -0.032 | 5 | 0.59 |
| P006 | 1 | 32 | 86.080 | 1.262 | -0.020 | 36 | 88.006 | 1.885 | -0.070 | 2 | 0.62 |
| P006 | 1 | 42 | 77.270 | 1.196 | 0.150 | 45 | 77.218 | 1.886 | -0.043 | 0 | 0.69 |
| P006 | 1 | 52 | 75.390 | 1.131 | 0.250 | 54 | 63.886 | 1.653 | 0.055 | -12 | 0.52 |
| P006 | 1 | 62 | 71.560 | 0.993 | 0.260 | 60 | 54.439 | 1.195 | 0.147 | -17 | 0.20 |
| P007 | 1 | 2 | 235.640 | 1.328 | 0.690 | 4 | 94.007 | 1.880 | -0.278 | -142 | 0.55 |
| P007 | 1 | 12 | 269.320 | 1.013 | 0.350 | 16 | 84.646 | 1.498 | 0.065 | -185 | 0.49 |
| P007 | 2 | 2 | 276.540 | 1.496 | 0.450 | 4 | 107.416 | 2.071 | -0.391 | -169 | 0.58 |
| P007 | 2 | 12 | 255.110 | 1.710 | 0.230 | 12 | 105.503 | 2.017 | -0.102 | -150 | 0.31 |
| P007 | 2 | 21 | 138.970 | 0.293 | 0.530 | 20 | 91.104 | 1.575 | -0.084 | -48 | 1.28 |
| P008 | 2 | 10 | 98.370 | 1.350 | -0.090 | 10 | 137.914 | 1.627 | -0.073 | 40 | 0.28 |
| P008 | 2 | 18 | 96.400 | 1.046 | -0.010 | 16 | 130.199 | 1.277 | 0.058 | 34 | 0.23 |
| P009 | 1 | 2 | 316.810 | 0.146 | -0.470 | 4 | 105.709 | 1.081 | -0.158 | -211 | 0.94 |
| P009 | 1 | 13 | 260.260 | 0.529 | 0.290 | 9 | 100.831 | 1.079 | -0.083 | -159 | 0.55 |
| P009 | 2 | 2 | 89.970 | 0.428 | -0.410 | 4 | 125.501 | 1.609 | -0.048 | 36 | 1.18 |
| P009 | 2 | 11 | 56.620 | 1.384 | 0.020 | 11 | 123.846 | 1.529 | 0.057 | 67 | 0.15 |
| P009 | 2 | 21 | 68.420 | 0.923 | 0.350 | 20 | 120.297 | 1.231 | -0.028 | 52 | 0.31 |
| P010 | 1 | 12 | 114.010 | 1.293 | -0.150 | 12 | 125.155 | 1.516 | -0.088 | 11 | 0.22 |
| P010 | 1 | 28 | 114.250 | 1.024 | -0.080 | 26 | 118.596 | 1.181 | -0.105 | 4 | 0.16 |
| P010 | 2 | 2 | 105.020 | 1.355 | -0.310 | 4 | 114.969 | 1.248 | -0.108 | 10 | -0.12 |
| P010 | 2 | 12 | 100.690 | 1.261 | -0.230 | 15 | 113.793 | 1.144 | -0.117 | 13 | -0.12 |
| P010 | 2 | 22 | 100.460 | 1.044 | -0.170 | 26 | 113.033 | 0.948 | -0.079 | 13 | -0.10 |
| P011 | 1 | 2 | 111.410 | 1.413 | -0.470 | 5 | 130.711 | 1.739 | -0.162 | 19 | 0.33 |

(Continued)

Table 8 (Continued)

| Range | Station | Prototype Depth ft | Prototype Phase | Prototype Amplitude | Prototype Average | Model Depth ft | Model Phase | Model Amplitude | Model Average | Model-Prototype Phase | Model-Prototype Amplitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Potomac River (Continued) | | | | | | |
| P011 | 1 | 12 | 127.690 | 1.443 | -0.370 | 11 | 131.002 | 1.557 | -0.080 | 8 | 0.11 |
| P011 | 1 | 22 | 123.430 | 1.313 | 0.330 | 21 | 131.865 | 1.363 | 0.053 | 8 | 0.05 |
| P011 | 1 | 32 | 118.650 | 1.167 | -0.060 | 29 | 129.569 | 1.184 | 0.051 | 11 | 0.02 |
| P012 | 1 | 2 | 126.840 | 1.293 | -0.430 | 4 | 128.439 | 1.446 | -0.163 | 2 | 0.15 |
| P012 | 1 | 12 | 137.260 | 1.264 | -0.420 | 12 | 128.235 | 1.583 | -0.202 | -9 | 0.32 |
| P012 | 1 | 22 | 133.110 | 1.224 | -0.420 | 22 | 142.160 | 1.577 | -0.207 | 9 | 0.35 |
| P012 | 1 | 32 | 137.870 | 1.164 | -0.400 | 32 | 136.505 | 1.473 | -0.092 | -1 | 0.31 |
| P012 | 1 | 42 | 131.410 | 1.035 | -0.340 | 42 | 140.609 | 1.200 | -0.032 | 9 | 0.17 |
| P012 | 1 | 52 | 134.790 | 0.915 | -0.300 | 52 | 134.989 | 1.107 | 0.043 | 0 | 0.19 |
| P013 | 1 | 2 | 146.560 | 0.945 | -0.680 | 4 | 144.149 | 1.135 | -0.255 | -2 | 0.41 |
| P013 | 1 | 25 | 130.520 | 0.577 | -0.490 | 22 | 142.340 | 0.902 | -0.240 | 12 | 0.33 |
| | | | | | Patuxent River | | | | | | |
| P01 | 1 | 22 | 19.710 | 0.717 | 0.020 | 12 | 347.445 | 0.496 | 0.029 | -32 | -0.22 |
| P01 | 1 | 22 | 19.710 | 0.717 | 0.020 | 22 | 333.778 | 0.472 | -0.063 | -46 | -0.25 |
| P01 | 1 | 32 | 342.710 | 0.686 | 0.260 | 32 | 329.363 | 0.534 | -0.088 | -13 | -0.15 |
| P01 | 1 | 40 | 356.880 | 0.502 | 0.270 | 40 | 339.174 | 0.248 | -0.056 | -18 | -0.25 |
| P01 | 2 | 4 | 351.330 | 1.065 | -0.370 | 4 | 339.580 | 0.917 | 0.097 | -12 | -0.15 |
| P01 | 2 | 12 | 356.290 | 0.911 | -0.240 | 12 | 348.384 | 0.703 | 0.183 | -8 | -0.21 |
| P01 | 2 | 22 | 5.530 | 0.901 | 0.000 | 22 | 344.974 | 0.630 | -0.027 | -21 | -0.27 |
| P01 | 2 | 32 | 354.690 | 0.819 | 0.280 | 32 | 331.674 | 0.592 | -0.100 | -23 | -0.23 |
| P01 | 2 | 42 | 358.060 | 0.686 | 0.350 | 42 | 317.590 | 0.575 | -0.054 | -40 | -0.11 |
| P02 | 1 | 4 | 226.670 | 0.804 | -0.550 | 4 | 4.854 | 0.504 | 0.147 | 138 | -0.30 |
| P02 | 1 | 12 | 351.950 | 0.570 | -0.250 | 12 | 347.248 | 0.541 | -0.002 | -5 | -0.03 |
| P02 | 1 | 22 | 343.160 | 0.458 | -0.140 | 23 | 319.463 | 0.509 | -0.034 | -24 | 0.05 |
| P02 | 2 | 4 | 12.120 | 1.050 | -0.110 | 4 | 338.034 | 0.811 | -0.064 | -34 | -0.24 |
| P02 | 2 | 12 | 15.740 | 0.849 | 0.060 | 12 | 341.142 | 0.685 | 0.094 | -35 | -0.16 |
| P02 | 2 | 22 | 15.930 | 0.670 | 0.220 | 22 | 353.432 | 0.667 | 0.033 | -22 | 0.00 |
| P02 | 2 | 32 | 357.020 | 0.581 | 0.320 | 32 | 349.713 | 0.837 | -0.050 | -7 | 0.26 |
| P02 | 2 | 42 | 7.840 | 0.592 | 0.310 | 42 | 343.096 | 0.826 | 0.004 | -25 | 0.23 |
| P02 | 2 | 52 | 0.600 | 0.637 | 0.280 | 52 | 342.570 | 0.836 | 0.018 | -18 | 0.20 |
| P02 | 2 | 62 | 16.510 | 0.670 | 0.200 | 62 | 342.117 | 0.789 | 0.073 | -34 | 0.12 |
| P03 | 1 | 4 | 12.380 | 0.882 | -0.090 | 4 | 352.865 | 0.500 | -0.074 | -20 | -0.38 |
| P03 | 1 | 12 | 17.980 | 0.860 | 0.040 | 12 | 352.396 | 0.532 | 0.009 | -26 | -0.33 |
| P03 | 1 | 22 | 1.570 | 0.357 | 0.110 | 22 | 337.857 | 0.477 | 0.028 | -24 | 0.12 |
| P04 | 1 | 4 | 32.760 | 0.932 | -0.100 | 4 | 7.153 | 0.621 | -0.084 | -26 | -0.31 |
| P04 | 1 | 12 | 33.780 | 1.014 | 0.190 | 12 | 5.572 | 1.000 | -0.083 | -28 | -0.01 |
| P04 | 1 | 22 | 17.480 | 0.973 | 0.320 | 22 | 345.111 | 0.935 | -0.103 | -32 | -0.04 |
| P04 | 1 | 32 | 6.180 | 0.604 | 0.170 | 32 | 344.519 | 0.931 | -0.169 | -22 | 0.33 |
| P04 | 2 | 4 | 357.870 | 1.096 | -0.070 | 4 | 0.738 | 0.928 | 0.110 | 3 | -0.17 |
| P04 | 2 | 12 | 41.270 | 0.686 | 0.070 | 10 | 3.020 | 0.744 | 0.113 | -38 | 0.06 |
| P05 | 1 | 4 | 55.110 | 1.638 | 0.040 | 4 | 13.262 | 1.318 | -0.142 | -42 | -0.32 |
| P05 | 1 | 12 | 42.150 | 0.655 | -0.060 | 9 | 359.602 | 0.863 | 0.048 | -43 | 0.21 |
| P05 | 2 | 4 | 46.760 | 1.473 | 0.280 | 4 | 14.200 | 1.600 | 0.147 | -32 | 0.13 |
| P05 | 2 | 12 | 48.700 | 1.383 | -0.130 | 12 | 13.235 | 1.470 | 0.158 | -35 | 0.09 |
| P05 | 2 | 22 | 54.510 | 1.184 | -0.050 | 16 | 15.430 | 1.352 | 0.087 | -39 | 0.17 |
| P06 | 1 | 4 | 48.410 | 1.024 | -0.170 | 4 | 17.417 | 0.906 | -0.079 | -31 | -0.12 |
| P06 | 1 | 12 | 62.600 | 0.840 | -0.180 | 12 | 23.699 | 0.980 | 0.014 | -39 | 0.14 |
| | | | | | Back River South | | | | | | |
| B01 | 1 | 12 | 140.430 | 1.439 | 0.140 | 12 | 149.657 | 0.653 | -0.054 | 9 | -0.79 |
| | | | | | Poquoson | | | | | | |
| P001 | 1 | 4 | 171.600 | 0.821 | -0.180 | 4 | 194.717 | 0.431 | -0.119 | 23 | -0.39 |
| | | | | | Mobjack Bay | | | | | | |
| M01 | 1 | 12 | 199.180 | 1.061 | 0.010 | 4 | 180.591 | 0.182 | 0.031 | -19 | -0.88 |
| M01 | 1 | 12 | 199.180 | 1.061 | 0.010 | 12 | 168.402 | 0.248 | 0.002 | -31 | -0.81 |
| M01 | 2 | 2 | 206.570 | 1.158 | -0.020 | 4 | 182.486 | 0.528 | -0.017 | -24 | -0.63 |
| M01 | 2 | 12 | 196.130 | 1.040 | 0.010 | 14 | 165.254 | 0.528 | -0.110 | -31 | -0.51 |
| M01 | 3 | 3 | 205.000 | 1.136 | -0.060 | 4 | 167.221 | 0.814 | 0.024 | -38 | -0.32 |
| M01 | 3 | 13 | 197.850 | 0.858 | -0.030 | 14 | 160.596 | 0.831 | 0.008 | -37 | -0.03 |
| M02 | 1 | 2 | 38.590 | 0.847 | -0.030 | 4 | 179.274 | 0.462 | 0.071 | 140 | -0.39 |
| M02 | 1 | 12 | 23.500 | 0.708 | -0.080 | 13 | 169.713 | 0.517 | 0.009 | 146 | -0.19 |
| M02 | 1 | 15 | 17.270 | 0.600 | -0.100 | 15 | 178.501 | 0.434 | 0.012 | 161 | -0.17 |
| M03 | 1 | 6 | 210.950 | 0.590 | -0.030 | 6 | 168.004 | 0.244 | -0.012 | -43 | -0.35 |
| M03 | 1 | 16 | 219.390 | 0.643 | 0.010 | 16 | 175.599 | 0.231 | -0.027 | -44 | -0.41 |

(Continued)

AD-A111 812 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
VERIFICATION OF THE CHESAPEAKE BAY MODEL.(U)
DEC 81 N W SCHEFFNER, L G CROSBY, D F BASTIAN
UNCLASSIFIED WES/TR/HL-81-14 NL

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A111812

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Table 8 (Continued)

| | | Prototype | | | | Model | | | | Model-Prototype | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Range | Station | Depth ft | Phase | Amplitude | Average | Depth ft | Phase | Amplitude | Average | Phase | Amplitude |
| | | | | | Mobjack Bay (Continued) | | | | | | |
| M03 | 1 | 24 | 195.370 | 0.386 | 0.070 | 21 | 171.379 | 0.151 | -0.016 | -24 | -0.24 |
| M04 | 1 | 2 | 192.480 | 0.804 | 0.010 | 4 | 162.432 | 0.123 | -0.011 | -30 | -0.68 |
| M04 | 1 | 12 | 181.670 | 0.665 | -0.070 | 13 | 166.803 | 0.120 | -0.006 | -15 | -0.55 |
| M04 | 1 | 20 | 204.970 | 0.590 | 0.020 | 20 | 167.518 | 0.115 | 0.001 | -37 | -0.48 |
| M05 | 1 | 2 | 221.420 | 0.986 | -0.050 | 4 | 175.754 | 0.326 | 0.017 | -46 | -0.66 |
| M05 | 1 | 12 | 195.850 | 0.976 | -0.050 | 11 | 171.660 | 0.371 | -0.034 | -24 | -0.61 |
| M05 | 1 | 19 | 218.620 | 0.568 | 0.040 | 14 | 171.432 | 0.175 | -0.010 | -47 | -0.39 |
| | | | | | Piankatank | | | | | | |
| PI01 | 1 | 20 | 237.440 | 0.329 | 0.280 | 18 | 232.827 | 0.088 | 0.003 | -5 | -0.24 |
| PI02 | 1 | 4 | 244.740 | 0.530 | -0.200 | 4 | 230.597 | 0.175 | 0.013 | -14 | -0.36 |
| PI02 | 1 | 14 | 224.350 | 0.494 | 0.040 | 12 | 239.962 | 0.090 | -0.003 | -15 | -0.40 |
| PI02 | 1 | 24 | 210.030 | 0.292 | 0.210 | 24 | 239.962 | 0.090 | -0.003 | 30 | -0.20 |
| | | | | | Great Wicomico | | | | | | |
| G01 | 1 | 4 | 271.388 | 0.993 | -0.090 | 4 | 227.550 | 0.126 | 0.027 | -44 | -0.24 |
| G01 | 1 | 14 | 261.230 | 0.577 | 0.270 | 13 | 222.212 | 0.086 | 0.007 | -39 | -0.36 |
| G01 | 1 | 17 | 258.630 | 0.233 | -0.130 | 15 | 242.160 | 0.070 | 0.005 | -16 | -0.40 |
| G02 | 1 | 14 | 272.570 | 0.486 | -0.080 | 13 | 235.624 | 0.235 | 0.007 | -37 | -0.20 |
| | | | | | South | | | | | | |
| S01 | 1 | 4 | 87.280 | 1.121 | 0.040 | 4 | 26.709 | 0.295 | 0.033 | -40 | -0.83 |
| S01 | 1 | 12 | 75.500 | 0.513 | 0.090 | 10 | 12.076 | 0.158 | -0.033 | -63 | -0.36 |
| S01 | 1 | 17 | 71.660 | 0.352 | 0.040 | 13 | 3.407 | 0.112 | -0.003 | -68 | -0.24 |
| S02 | 1 | 4 | 74.770 | 0.427 | 0.040 | 5 | 33.958 | 0.092 | -0.020 | -40 | -0.34 |
| S02 | 1 | 12 | 53.590 | 0.150 | 0.030 | 14 | 48.061 | 0.102 | -0.008 | -5 | -0.05 |
| | | | | | Severn | | | | | | |
| SE01 | 1 | 4 | 89.700 | 0.350 | 0.130 | 4 | 89.296 | 0.373 | 0.174 | 0 | 0.02 |
| SE01 | 1 | 18 | 84.310 | 0.196 | 0.110 | 12 | 62.565 | 0.121 | 0.016 | -22 | -0.08 |
| SE01 | 1 | 18 | 84.310 | 0.196 | 0.110 | 16 | 71.039 | 0.123 | -0.002 | -13 | -0.07 |
| SE02 | 1 | 4 | 49.540 | 0.350 | -0.110 | 6 | 39.221 | 0.047 | 0.021 | -10 | -0.30 |
| SE02 | 1 | 18 | 93.890 | 0.041 | 0.130 | 17 | 56.356 | 0.050 | -0.000 | -37 | 0.01 |
| SE02 | 1 | 18 | 93.890 | 0.041 | 0.130 | 25 | 56.356 | 0.050 | -0.000 | -37 | 0.01 |
| SE02 | 2 | 4 | 30.000 | 0.350 | -0.040 | 4 | 67.050 | 0.089 | -0.003 | 37 | -0.26 |
| SE02 | 2 | 22 | 65.850 | 0.134 | 0.090 | 20 | 45.647 | 0.089 | 0.002 | -20 | -0.05 |
| | | | | | Magothy | | | | | | |
| MA01 | 1 | 4 | 94.800 | 0.618 | -0.070 | 4 | 79.280 | 0.641 | 0.107 | -15 | 0.02 |
| MA01 | 1 | 12 | 95.650 | 0.532 | 0.120 | 12 | 83.292 | 0.385 | 0.127 | -12 | -0.15 |
| MA01 | 1 | 18 | 93.060 | 0.438 | 0.170 | 17 | 81.237 | 0.217 | 0.042 | -12 | -0.22 |
| MA02 | 1 | 4 | 113.850 | 0.280 | -0.030 | 4 | 104.763 | 0.095 | 0.006 | -9 | -0.19 |
| MA02 | 1 | 15 | 128.800 | 0.031 | 0.180 | 14 | 102.840 | 0.089 | 0.003 | -26 | 0.06 |
| | | | | | Patapsco | | | | | | |
| PR01 | 1 | 2 | 103.940 | 0.390 | -0.070 | 4 | 69.740 | 0.204 | -0.077 | -34 | -0.10 |
| PR01 | 1 | 14 | 111.430 | 0.361 | -0.170 | 12 | 44.393 | 0.144 | -0.023 | -67 | -0.22 |
| PR01 | 2 | 2 | 89.550 | 0.444 | -0.040 | 4 | 115.722 | 0.115 | 0.006 | 26 | -0.33 |
| PR01 | 2 | 13 | 102.540 | 0.389 | -0.190 | 12 | 101.163 | 0.210 | -0.053 | -1 | -0.16 |
| PR01 | 3 | 2 | 77.140 | 0.556 | 0.090 | 4 | 79.093 | 0.260 | 0.149 | 2 | -0.30 |
| PT01 | 3 | 12 | 101.590 | 0.407 | -0.060 | 13 | 70.336 | 0.246 | 0.116 | -31 | -0.16 |
| PR01 | 3 | 22 | 137.970 | 0.167 | -0.040 | 24 | 112.494 | 0.355 | 0.184 | -25 | 0.19 |
| PR01 | 3 | 32 | 150.320 | 0.213 | 0.070 | 34 | 79.245 | 0.268 | 0.132 | -71 | 0.08 |
| PR01 | 3 | 38 | 126.760 | 0.167 | 0.130 | 11 | 62.928 | 0.199 | 0.105 | -64 | 0.02 |
| PR02 | 1 | 2 | 128.440 | 0.194 | -0.360 | 4 | 102.506 | 0.097 | -0.003 | -25 | -0.09 |
| PR02 | 1 | 14 | 81.140 | 0.306 | -0.210 | 13 | 90.698 | 0.175 | -0.862 | 10 | -0.14 |
| PR02 | 2 | 2 | 149.140 | 0.093 | -0.040 | 4 | 95.253 | 0.114 | -0.054 | -54 | 0.02 |
| PR02 | 2 | 22 | 99.750 | 0.241 | 0.190 | 24 | 93.551 | 0.151 | 0.017 | -6 | -0.09 |
| PR02 | 2 | 32 | 90.710 | 0.269 | 0.400 | 35 | 94.204 | 0.165 | -0.025 | 3 | -0.11 |
| PR02 | 2 | 39 | 69.190 | 0.259 | 0.330 | 41 | 97.007 | 0.131 | -0.042 | 28 | -0.13 |
| PR03 | 1 | 2 | 142.490 | 0.083 | -0.430 | 4 | 103.777 | 0.011 | -0.064 | -38 | -0.07 |
| PR03 | 1 | 12 | 112.920 | 0.093 | 0.050 | 13 | 73.673 | 0.033 | -0.053 | -39 | -0.06 |
| PR03 | 1 | 22 | 90.640 | 0.074 | 0.200 | 24 | 62.590 | 0.023 | -0.048 | -28 | -0.05 |
| PR03 | 1 | 32 | 116.410 | 0.093 | 0.060 | 34 | 57.553 | 0.083 | 0.008 | -58 | -0.01 |
| PR03 | 1 | 39 | 80.110 | 0.028 | 0.049 | 40 | 61.802 | 0.097 | -0.021 | -18 | -0.07 |
| PR03 | 2 | 2 | 135.640 | 0.065 | -0.280 | 4 | 91.253 | 0.039 | -0.089 | -45 | -0.02 |
| PR03 | 2 | 12 | 122.890 | 0.102 | 0.040 | 12 | 134.967 | 0.160 | -0.015 | 11 | 0.06 |
| PR03 | 2 | 22 | 93.370 | 0.074 | 0.040 | 19 | 86.643 | 0.041 | -0.008 | -6 | -0.03 |

(Continued)

Table 8 (Continued)

| Range | Station | Prototype Depth ft | Prototype Phase | Prototype Amplitude | Prototype Average | Model Depth ft | Model Phase | Model Amplitude | Model Average | Model-Prototype Phase | Model-Prototype Amplitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Back River North | | | | | | |
| BN01 | 1 | 4 | 119.040 | 0.546 | -0.080 | 3 | 125.132 | 0.378 | 0.043 | 6 | -0.17 |
| | | | | | Middle River | | | | | | |
| MR01 | 1 | 4 | 136.000 | 0.751 | 0.100 | 4 | 132.334 | 0.204 | 0.045 | -4 | -0.55 |
| | | | | | Gun Powder | | | | | | |
| GR01 | 1 | 2 | 123.680 | 0.815 | 0.110 | 4 | 122.308 | 0.652 | 0.025 | -1 | -0.16 |
| GR01 | 1 | 12 | 128.520 | 0.648 | -0.040 | 12 | 118.823 | 0.586 | 0.017 | -10 | -0.06 |
| GR01 | 1 | 20 | 125.680 | 0.435 | 0.020 | 18 | 102.874 | 0.227 | 0.053 | -23 | -0.21 |
| | | | | | Bush | | | | | | |
| BR01 | 1 | 4 | 166.640 | 1.110 | -0.070 | 4 | 182.517 | 0.597 | 0.186 | 16 | -0.51 |
| BR01 | 1 | 8 | 160.940 | 0.630 | 0.100 | 8 | 164.521 | 0.429 | 0.184 | 4 | -0.20 |
| | | | | | Susquehanna | | | | | | |
| SU01 | 1 | 4 | 189.810 | 0.540 | -0.240 | 4 | 197.485 | 0.423 | 0.582 | 0 | -0.12 |
| SU01 | 1 | 14 | 191.120 | 0.220 | -0.160 | 12 | 195.595 | 0.365 | -0.508 | 4 | 0.15 |
| SU01 | 2 | 12 | 207.630 | 0.251 | -0.100 | 12 | 196.828 | 0.446 | -0.673 | -11 | 0.20 |
| SU01 | 2 | 22 | 201.380 | 0.213 | -0.070 | 22 | 188.376 | 0.370 | 0.641 | -13 | 0.16 |
| SU01 | 2 | 26 | 133.720 | 0.190 | -0.060 | 24 | 196.271 | 0.346 | 0.636 | 62 | 0.16 |
| | | | | | North East | | | | | | |
| NE01 | 1 | 4 | 196.240 | 1.040 | 0.010 | 4 | 195.226 | 1.085 | -0.059 | -1 | 0.05 |
| NE01 | 1 | 11 | 206.370 | 0.899 | -0.020 | 9 | 193.383 | 0.855 | -0.009 | -13 | -0.04 |
| | | | | | Elk | | | | | | |
| E01 | 1 | 4 | 197.580 | 1.421 | -0.100 | 5 | 200.515 | 1.549 | 0.030 | 3 | 0.13 |
| E01 | 1 | 12 | 192.900 | 1.178 | -0.030 | 10 | 198.308 | 1.459 | 0.062 | 5 | 0.28 |
| E01 | 1 | 18 | 195.370 | 0.836 | -0.820 | 15 | 198.185 | 1.247 | 0.009 | 3 | 0.41 |
| E02 | 1 | 4 | 196.580 | 0.799 | -0.060 | 4 | 209.009 | 0.619 | -0.043 | 12 | -0.18 |
| E02 | 1 | 8 | 194.260 | 0.644 | -0.030 | 6 | 212.639 | 0.532 | -0.046 | 18 | -0.11 |
| | | | | | Bohemia | | | | | | |
| B001 | 1 | 4 | 195.900 | 0.699 | 0.010 | 5 | 185.909 | 0.314 | -0.069 | -10 | -0.39 |
| | | | | | Sassafrass | | | | | | |
| SA01 | 1 | 4 | 177.920 | 0.727 | -0.060 | 4 | 174.022 | 0.448 | 0.002 | -4 | -0.28 |
| SA02 | 1 | 4 | 178.830 | 0.696 | -0.130 | 4 | 142.045 | 1.051 | -0.372 | -37 | 0.35 |
| SA02 | 1 | 12 | 188.230 | 0.516 | 0.010 | 12 | 177.163 | 0.437 | 0.024 | -11 | -0.08 |
| SA02 | 1 | 22 | 178.278 | 0.461 | 0.130 | 22 | 170.787 | 0.369 | 0.042 | -7 | -0.09 |
| SA02 | 1 | 32 | 171.860 | 0.399 | 0.220 | 32 | 170.406 | 0.282 | 0.005 | -1 | -0.12 |
| SA02 | 1 | 37 | 167.100 | 0.336 | 0.240 | [illegible] | 171.909 | 0.247 | -0.068 | 4 | -0.09 |
| | | | | | Chester | | | | | | |
| CH01 | 1 | 4 | 148.000 | 0.821 | -0.170 | 4 | 103.293 | 0.455 | 0.072 | -45 | -0.37 |
| CH01 | 1 | 12 | 146.120 | 0.821 | -0.070 | 12 | 111.519 | 0.326 | -0.041 | -35 | -0.49 |
| CH01 | 1 | 22 | 140.180 | 0.726 | 0.010 | 22 | 106.529 | 0.336 | -0.021 | -34 | -0.39 |
| CH01 | 1 | 32 | 145.720 | 0.663 | 0.090 | 32 | 99.899 | 0.294 | 0.016 | -46 | -0.37 |
| CH01 | 1 | 42 | 135.500 | 0.642 | 0.170 | 42 | 89.644 | 0.424 | 0.038 | -46 | -0.22 |
| CH01 | 1 | 52 | 130.620 | 0.610 | 0.230 | 51 | 83.566 | 0.329 | 0.033 | -47 | -0.28 |
| CH02 | 1 | 4 | 122.280 | 0.894 | -0.090 | 4 | 109.673 | 0.256 | 0.004 | -13 | -0.64 |
| CH02 | 1 | 25 | 101.330 | 0.358 | 0.290 | 21 | 109.067 | 0.132 | 0.010 | 8 | -0.23 |
| CH02 | 2 | 4 | 149.100 | 1.057 | -0.310 | 4 | 128.027 | 0.327 | -0.071 | -21 | -0.73 |
| CH02 | 2 | 14 | 149.480 | 0.577 | 0.168 | 14 | 119.504 | 0.170 | 0.013 | -30 | -0.41 |
| CH02 | 2 | 26 | 124.010 | 0.278 | 0.390 | 26 | 119.482 | 0.258 | 0.098 | -5 | -0.02 |
| CH03 | 1 | 4 | 113.570 | 0.642 | -0.020 | 4 | 106.734 | 0.369 | -0.160 | -7 | -0.27 |
| CH03 | 1 | 11 | 127.020 | 0.526 | 0.060 | 11 | 112.311 | 0.473 | -0.211 | -15 | -0.05 |
| CH04 | 1 | 4 | 120.710 | 1.260 | -0.330 | 4 | 150.073 | 1.535 | -0.215 | 29 | 0.28 |
| CH04 | 1 | 12 | 155.900 | 0.983 | -0.040 | 12 | 136.178 | 1.224 | -0.101 | -20 | 0.24 |
| CH04 | 1 | 32 | 143.540 | 0.908 | 0.600 | 32 | 157.039 | 0.250 | -0.068 | 13 | -0.66 |
| CG04 | 1 | 44 | 145.060 | 0.780 | 0.580 | 44 | 157.807 | 0.258 | -0.016 | 13 | -0.52 |
| | | | | | Wye | | | | | | |
| W01 | 1 | 4 | 33.230 | 0.981 | -0.090 | 4 | 64.199 | 0.820 | -0.105 | 31 | -0.16 |
| W01 | 1 | 12 | 35.250 | 0.876 | -0.060 | 12 | 58.245 | 0.472 | -0.013 | 23 | -0.40 |
| W01 | 1 | 22 | 35.460 | 0.815 | -0.040 | 23 | 59.621 | 0.371 | -0.044 | 24 | -0.44 |
| W01 | 1 | 32 | 35.300 | 0.815 | -0.020 | 33 | 46.945 | 0.528 | 0.005 | 12 | -0.29 |
| W01 | 1 | 42 | 30.180 | 0.806 | -0.010 | 44 | 55.634 | 0.620 | 0.054 | 25 | -0.19 |

(Continued)

Table 8 (Concluded)

| Range | Station | Prototype Depth ft | Prototype Phase | Prototype Amplitude | Prototype Average | Model Depth ft | Model Phase | Model Amplitude | Model Average | Model-Prototype Phase | Model-Prototype Amplitude |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Wye** | | | | | | |
| W01 | 1 | 51 | 25.340 | 0.762 | 0.010 | 53 | 24.633 | 0.366 | 0.129 | -1 | -0.40 |
| W02 | 1 | 4 | 30.940 | 0.718 | -0.040 | 4 | 52.794 | 0.534 | -0.038 | 22 | -0.13 |
| W02 | 1 | 12 | 33.160 | 0.604 | 0.030 | 12 | 35.017 | 0.235 | 0.044 | 2 | -0.37 |
| W02 | 1 | 21 | 34.340 | 0.473 | 0.080 | 19 | 58.113 | 0.178 | 0.048 | 24 | -0.29 |
| | | | | | **Miles** | | | | | | |
| MI01 | 1 | 4 | 35.340 | 0.692 | 0.070 | 4 | 78.543 | 0.384 | 0.170 | 43 | -0.31 |
| MI01 | 1 | 12 | 4.710 | 0.429 | 0.100 | 12 | 55.051 | 0.164 | 0.045 | 50 | -0.27 |
| MI01 | 1 | 32 | 31.270 | 0.412 | 0.130 | 32 | 54.473 | 0.154 | -0.024 | 23 | -0.26 |
| MI02 | 1 | 4 | 219.710 | 0.420 | -0.170 | 4 | 27.604 | 0.099 | 0.006 | -192 | -0.32 |
| | | | | | **Tred Avon** | | | | | | |
| TA01 | 1 | 4 | 22.000 | 0.658 | -0.040 | 4 | 20.685 | 0.450 | 0.084 | -1 | -0.21 |
| TA01 | 1 | 12 | 21.050 | 0.423 | 0.140 | 12 | 14.388 | 0.394 | 0.107 | -7 | -0.03 |
| TA01 | 1 | 23 | 38.300 | 0.249 | 0.160 | 27 | 337.479 | 0.156 | 0.012 | 61 | -0.09 |
| TA02 | 1 | 4 | 22.470 | 0.529 | 0.110 | 4 | 23.002 | 0.307 | 0.050 | 1 | -0.22 |
| TA02 | 1 | 14 | 22.980 | 0.386 | 0.030 | 14 | 4.035 | 0.352 | -0.057 | -19 | -0.03 |

(Sheet 7 of 7)

APPENDIX A

PROTOTYPE DATA COLLECTION

## Introduction

### Purpose and organization

1. The primary purpose of the prototype data collection is to provide the necessary data with which to properly calibrate and verify the Chesapeake Bay model. The types of data deemed necessary for this purpose include: tidal elevations, current velocities and directions, salinities, freshwater discharges, and meteorological conditions that include wind. When combined, these groups of data are used to define several sets of known prototype conditions to which the model can be verified.

2. The collection of the above data was managed by the U. S. Army Engineer District, Baltimore (NAB). The size of the bay, however, made it difficult for a single agency to collect the required prototype data during a common time period primarily due to the amount of manpower and equipment that would be needed. Therefore, the data collection task was contracted by NAB to various groups. The tidal elevation data collection was conducted primarily by the National Oceanographic and Atmospheric Administration (NOAA), and in part by the Virginia Institute of Marine Science (VIMS). Velocity and salinity data collections were accomplished by VIMS; the Chesapeake Bay Institute, Johns Hopkins University (CBI); and the Chesapeake Biological Laboratory, University of Maryland (CBL). Freshwater discharges for the tributaries were computed by NAB from stream-gaging information obtained from the U. S. Geological Survey (USGS) and the Maryland State Department of Natural Resources. Meteorological data were obtained from monthly logs of weather stations furnished by the National Weather Service, through NOAA.

3. Generally, data were collected over the years 1970 through 1974 at various discrete time periods. All collected data were supplied to the U. S. Army Engineer Waterways Experiment Station (WES) for review and analysis. The remainder of this appendix will describe the data collection procedures and the localities and time of data collection.

## Tide Data

### Equipment used

4. Tide gages established by National Ocean Survey (NOS) were of a stilling-well type. Water level is sensed and recorded by a Fisher and Porter paper-punchtape recording device which was usually connected to a float mechanism located in a stilling well. The group of gages established by VIMS were of the Boon type which incorporates a float-counterweight mechanism connected to a geared drum attached to a multi-turn precision potentiometer. The potentiometer in turn was connected to a strip chart recorder. Both types of instruments produce measurements within ±0.01 ft.

### Locations and periods of collection

5. Tide gages for prototype data collection were distributed at 75 locations covering the main bay and its tributaries. These locations are shown in Figure 2 in the main body of this report. Although sampling did not start simultaneously nor was it always synoptic, the tidal height data-gathering program began in late 1970 and was continued into 1974. The majority of data were collected during 1971 and 1972. The time span for which data were collected for each station (data were received from 72 stations) is graphically depicted in Plate A1. No data were obtained at sta 1, 39, or 57 for the data collection period for the following reasons:

- a. Sta 1 (Virginia Beach) was destroyed by a storm before the data collection program was begun.
- b. Sta 39 (Piney Point) was located adjacent to an oil distribution pier. Since no electrically operated devices could be present in the area because of fire hazard, sta 39 was never put into operation.
- c. Sta 57 (Cove Point) was operable; however, consistent gage malfunctions rendered the data unusable.

Harmonic analysis was provided at NOAA for sta 1 and 57 based on data from a period other than the prototype data collection period.

### Collection procedures

6. Prior to data collection, all tide gages were checked for zero

datum with respect to the National Geodetic Vertical Datum of 1929, adjusted in 1971. Data in the form of punched-tape rolls or paper traces were periodically collected by personnel of NOS and directed to the NOS office in Washington, D. C. Here the data were reduced and transferred to magnetic tapes. The tapes were then forwarded to WES for analysis. The data on the tapes were recorded to the nearest 0.01 ft at half-hour or less increments. During the data collection program, approximately 1000 miles of double-run, first-order leveling was performed by NOS to tie the tide gages in the bay to a common datum.

Harmonic analysis

7. In addition to collection of raw tidal elevation data, NOS was contracted to provide 1-yr harmonic analyses for the tidal stations having at least 1 yr of data (Table A1). This analysis provided the phase angles and amplitudes of the 37 primary constituents. Twenty-nine day harmonic analyses for 24 primary constituents were provided for the tidal stations with less than 1 yr of data with an attempt to provide an analysis for each season if possible. In addition to the above analyses, a 1-yr harmonic analysis was provided for sta 1 for the period January 1968-January 1969.

## Velocity Data

Data collection reports

8. Velocity data collection for the Chesapeake Bay Study was a combined effort of CBI, CBL, and VIMS. VIMS efforts were primarily concentrated in the Virginia portion of the bay, on the James, York, and Rappahannock Rivers and other Virginia tributaries. Three reports were issued by VIMS concerning their collection procedures: Ruzecki (1974), Ruzecki and Markle (1974), and Jacobson (1974). CBL combined its resources with CBI to collect data in the Potomac River, various other upper bay tributary stations, and main bay ranges in the lower, middle, and upper portions of the bay. The data collection procedures were published by CBI in three reports: Klepper (1972a), Klepper (1972b), and Michael (1975). The areas of report coverage are depicted graphically in Plate A2.

Equipment used

9. Three types of recording velocity meters were used in collecting the velocity data: (a) Model 1381 Braincon histogram current meters, (b) Model 105 Endeco recording meters, and (c) Model C Aanderaa recording current meters. The Braincon meter measured velocity by use of a Savonious rotor; velocity direction was determined by a magnetic compass attached to a vane aligned to the current direction. The data output of the rotor speed and meter direction were sampled over discrete time intervals and recorded on 16-mm film. The Endeco meter's operation was similar to the Braincon with the exception that it was attached to the meter chain by a swivel, allowing the entire meter body to align itself with current direction. The Endeco also recorded its output on 16-mm film. The Aanderaa meter, in addition to velocity magnitude and direction, also contained a conductivity probe and a thermistor. Like the other two meters, velocity magnitude was measured by a rotor, and direction was measured by a magnetic compass connected to a fin. However, the Aanderaa recorded its data on a magnetic tape contained in the unit. All three types of meters provided measurements within ±0.1 fps for velocity magnitude and ±5 degrees for direction. Time references were accurate to ±5 min for the Braincon meter, ±10 min for the Endeco, and ±20 min for the Aanderaa.

10. Braincon meters were used for the majority of velocity measurements made during the entire study. Endeco meters were used in CBI's 1973 deployments and were used for surface measurements only. Aanderaa meters were used only at stations located in Pocomoke Sound, Big Annemessex River, and Manokin River.

Locations and periods of collection

11. Velocity data were collected at 205 sampling locations. The number of depths for which data were taken at a station depended upon the bottom depth, and varied from 1 depth per station for shallow areas to as many as 12 depths per station for deeper areas. At the 205 stations, the total number of depths at which velocities were taken was 770. Different stations were sampled nonsynoptically during 28 discrete time periods ranging from approximately 3 days to the extreme

of 15 days during 1970 through 1973. Station locations and corresponding sampling periods are shown in Plates A3-A6. Depths at which velocities were measured at each station are contained in Table A2. As can be observed from the legend of Plates A3-A6, velocity data collection, collected in deployment groups, lasted an average of 5 days.

Meter deployment methods

12. All meters at a velocity station, except the meter located near the surface, were deployed in a similar manner during the data collection periods. At each velocity station, the meters used were spaced at specific intervals (depths) and taut-moored together to form a meter chain. This chain was placed overboard and anchored to the bottom by an iron railroad car wheel or by a lead weight. Once in position, the meter chain was left in place generally for 3 to 5 days.

13. As mentioned above, the surface meter was not always attached to the meter chain in the same manner. CBI used three different methods to attach the surface meter. During the first data collection deployments, a Braincon meter was suspended from the surface by a Styrofoam disk and slack-moored to the remaining chain; this arrangement was later abandoned due to possible effects of wave contamination. In later deployments the Braincon meter was attached to a plank-on-edge (POE) buoy which looked rather like a large fin. The POE mounted meter was then slack-moored to the remaining chain. During deployments using the Endeco meters, the Endeco meter was suspended from the surface by a Styrofoam float, but unlike the other two types of arrangements it was taut-moored to the remaining chain. VIMS used a taut-moored POE-type Braincon meter mounting.

Collection procedures

14. At the beginning of each of the collection periods, stations were located and identified using visual sighting and computations of latitude and longitude, and a string of current meters anchored in place. Generally, the string was placed with the bottom meter located 2 to 4 ft from the bottom, and the surface meter 2 to 4 ft from the surface. The remaining meters in the chain were generally spaced at 10-ft intervals. Data were automatically recorded at 10- or 20-min intervals, so a continuous record of measurements was provided over the deployment period.

The raw data recorded by the meters were processed by VIMS and CBI and reduced to current magnitude and direction over time for each data measurement. Flood and ebb current directions were assigned (plus and minus) to the magnitudes based on compass direction with respect to the transect of the velocity range. This information, along with necessary station locations and depths, was generally recorded on magnetic tapes and furnished to WES for analysis.

## Salinity Data

### Equipment used

15. Throughout their portion of the study, CBI and CBL used three means of salinity measurement. For the majority of salinity stations the CBI Induction Conductivity Temperature Indicators (ICTI) were used (Schiemer and Pritchard 1961). The ICTI is an in situ induction-type conductivity probe thermistor. In operation the meter was suspended from a cable hoist and lowered to the measurement depth. Onboard readout indicators provided the conductivity and temperature values. Salinity was computed by the following relation:

$$\text{Salinity (ppt)} = 0.03 + 1.805 \text{ chlorinity (ppt)}$$

The accuracy of this device is not stated but assumed to be $\pm 0.1$ ppt.

16. The second type of measurement device used was a Beckman RS-5-3 Industrial Salinometer. This meter is also an in situ induction-type conductivity probe coupled with a thermistor. The conductance probe and thermistor are combined through circuitry to provide direct salinity readings. The salinometer was also suspended from a cable hoist and lowered to the measurement depths. The stated accuracy of this instrument was $\pm 0.5$ ppt.

17. The third type of measuring device used was a model Aanderaa current meter with conductivity and temperature sensors. As this meter was also used for velocity measurements, it was deployed in a meter chain as previously described.

18. The method used by VIMS to obtain salinities consisted of collecting water samples and conducting a laboratory analysis. The samples were obtained by lowering a string of weighted Frautschy bottles spaced in specified intervals. These bottles were made from 2-ft sections of 2-in.-diam PVC pipe. Once the string was lowered into position, the bottles were closed by a messenger (a weight dropped down the string). The string was then raised back up onboard the vessel and a sample storage bottle was filled with water from each pipe. Surface samples were obtained by dipping a sample storage bottle overboard. The samples were then taken to the laboratory where they were measured for salt concentration by use of a Beckman RS7-A laboratory-type salinometer. The stated accuracy of this instrument is $\pm 0.01$ ppt.

Location and periods of tidal-cycle salinity data collection

19. Salinity sampling over complete (13 hr) tidal cycles was conducted at 199 stations. These stations were the same as those used for velocity measurements with the exception of velocity stations above the known 0-ppt isohaline in the James and Potomac Rivers and were collected concurrently with the velocity measurements. Locations and periods of collection are shown in Plates A3-A6. In general, each location was sampled every half hour for 13 consecutive daylight hours on each of 3 consecutive days. The sampling depths used by CBL and CBI were the same as those used for velocity measurements; VIMS data were taken in 2-m increments from the surface. The depths sampled at each station are listed in Table A3; a total of 781 points were sampled.

Same slack cruises

20. In addition to the above collected tidal-cycle data, several slack-water salinity cruises were conducted on the main bay and the Potomac, James, York, and Rappahannock Rivers. These cruises were intended to provide (a) a "synoptic" view of salinity within a portion of the estuary and (b) a time-history of salinity change due to freshwater inflow. A cruise was generally conducted once a month for a period of 1 year, although some months were either skipped or sampled more than once a month. The stations monitored were located along the main channel

center lines and are shown in Plate A7. The months each station was sampled are listed in Table A4. While in principle each cruise was to collect samples at either the same slack-before-flood or slack-before-ebb condition, boat logistics made this impossible. Thus, all cruises contain a mixture of same slack conditions and of times other than slack conditions, occurring over a period of 1 or 2 days depending upon system sampled and density of sampling.

## Freshwater Inflow Data

### Procedure

21. For the purpose of providing freshwater inflow data for the Chesapeake Bay model, a computational method was developed by NAB. This was necessitated by the lack of stream-gaging information at many tributaries to the bay system other than stream gages located above head of tide for the tributary system. In this method, inflow for a drainage basin without stream gages was determined by proportioning inflows measured at USGS stream-gaging stations at adjacent drainage areas. While the computations included the effects of reservoirs, major water diversions, and major sewage and industrial discharges, no attempts were made to include rainfall over the water portion of the bay or groundwater inflows.

22. For computational purposes, the bay and its tributaries were divided into 126 drainage basins. The flow for each of these 126 basins was then computed by the distribution technique above, using 70 stream-gaging stations.

### Collection periods

23. Using streamflow records maintained by the USGS for the 70 gaging stations, mean daily hydrographs were computed for each of the 126 drainage basins for the period 1 October 1969 through 31 October 1973.

## Wind Data

### Collecting agencies and equipment

24. Wind data in the form of surface weather observations were obtained from the National Climate Center of NOAA. The data were provided in the form of copies of daily weather observation data sheets compiled by observers at weather stations. A description of the types of equipment used was not provided to WES. However, it is assumed that equipment used was compatible with that found at a typical weather observation station.

### Locations and periods of observation

25. Wind data were supplied for 24 stations located in various areas around the bay. These stations consisting of airfields, coast guard stations, and weather stations are listed and locations are shown in Figure 5 in the main body of this report.

26. The data were provided for seven periods: 1 Jun-30 Nov 70; 1 Apr-31 Aug 71; 1 Oct-31 Oct 71; 3 Oct-26 Oct 72; 1 Apr-12 May 73; 1 Jul-19 Jul 73; and 1 Aug-20 Aug 73. As with any data collection, several stations do not have data for all the periods stated. Three stations, Phillips Army Airfield, Patuxent River, and Norfolk-USFWC, have complete daily observations for 1970-73.

27. In general, all stations provided wind speed and direction usually observed on an hourly basis. However, no indication was given as to the distance above the ground the wind was observed.

## Evaluation of Data

### Tidal height

28. There are data gaps from several hours to several days to several months in the tidal records. These gaps present problems in performing tidal harmonic analyses on the data. Ideally, the best continuous record length for such analysis is 365 days. However, good results can be obtained from a 30-day analysis; the minimum acceptable

record length for analysis is 15 days. Of the 72 locations where tidal data were collected only two have a continuous 365-day record and yet there is not one 15-day period common to all the locations.

29. If data reductions of velocity and salinity measurements are to be made with reference to tidal data, data gaps present difficulties in rendering compatible data sets. One method available to provide a compatible tide for all locations at a single time is to construct a tide based on the $M_2$ harmonic constituent. This approach was used as explained in paragraph 54 of the main text.

30. Maximum allowable leveling errors as published by the Department of Commerce are 0.034 ft in 5000 ft between benchmarks. Sturges (1967) has concluded that leveling errors on the east coast amount to 3.5 cm (1.37 in.)/degree latitude. These potential errors must be taken into account during the establishment of tidal datums for the 72 tidal stations located on the model.

Velocity

31. Several known sources of error exist in the velocity data. An error may exist in the velocity directions obtained in the early deployments (1970 and 1971). These deployments involved anchoring the meter strings with iron railroad car wheels. It is probable that the wheel interfered with the magnetic compass in the Braincon meters. This would indicate possible errors in current directions, especially in meters positioned near the bottom of the chain. The possibility exists that some additional errors may exist in reported velocity magnitudes. The two sources of this error are application of meter calibration coefficients to recorded data and Savonious rotor "pump-up" due to wave induced rotations.

32. Velocity data were collected during 28 different 3- to 5-day periods. Exceptions to this are the lower three ranges of the James River, which were occupied once during 1971 and once during 1973; Potomac River Ranges 3 and 11, which were occupied once during 1970 and once during 1971; and bay Range 5, sta 4, which was occupied once during 1972 and once during 1973.

33. Collection of velocity data at these different time periods guarantees a multitude of tidal, freshwater inflow and wind conditions. Thus, a single tidal-inflow condition does not exist for overall adjustment of the model. The consequence is a set of 28 different model inputs which are nonrelatable, both spatially and temporally. The alternative to this approach was the development of an $M_2$ velocity as described in paragraph 68 of the main text.

Salinity

34. Some comments made about velocity data above are also applicable to the salinity data, as both types of data at each station were generally collected concurrently. Three basic exceptions exist. While the velocity data were obtained as a continuous 3- to 5-day record, the salinity data were collected in 13-hr segments each collection day (daylight hours). Also, these collections varied from only 1 day to several and were not conducted for the same number of stations and depths as velocity measurements. The exception to this situation is the set of same slack salinity surveys which provide quasi-synoptic data sets.

35. While it is possible to analytically construct an $M_2$ constituent-based velocity data set, the possibility of constructing a similar set does not exist for the salinities. This is because (a) the salinity records with 11-hr gaps (nighttime hours) cannot be subjected to harmonic analysis, and (b) salinity does not vary about a mean nearly as consistently as do the tide and velocity.

Freshwater inflow data

36. Of all data sets furnished, freshwater inflow data are perhaps the most contiguous set, due to the fact that data are based on drainage area sizes and records of USGS stream-gaging stations. Potential errors in this data set would derive from assumptions used in distributing the data from the 70 available stream gages over 126 drainage basins.

Wind data

37. Generally the wind data collected are sufficient to evaluate wind conditions during specific times of velocity and salinity data collection. For possible use in evaluating long-term wind effects on tide

heights, only 3 of the 24 stations have continuous data; the other stations were collected (a) several months at a time, (b) Monday through Friday, or (c) for only 8 hr a day.

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Table A1

Tidal Stations Harmonic Analysis

| System | Tide Station Numbers |
|---|---|
| Main Bay | 2, 17, 22, 34, 36, 53, 58, 59, 62, 64, 67, 68, 69, 70, 72, 75 |
| James River | 3, 4, 5, 6, 8, 9, 11, 12, 14 |
| York River | 18, 19, 20, 21 |
| Rappahannock River | 26, 27, 28, 29, 30, 31, 32, 33 |
| Potomac River | 38, 42, 44, 45, 47, 49, 74 |
| Patuxent River | 53, 54, 56 |
| Choptank River | 60, 61 |
| Chester River | 66 |

Table A2

Velocity Stations and Depths

| Location Range | Station | Meter Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Main Bay | CB00-01 | 4, 12, 22, 32 | 36 |
| | -02 | 4, 12, 22, 32, 42, 52, 62, 68 | 75 |
| | -03 | 4, 12, 22, 32, 38 | 41 |
| | -04 | 4, 12, 22, 30 | 33 |
| | -05 | 4, 12, 17 | 20 |
| | -06 | 4, 12 | 15 |
| | -07 | 4, 12, 18 | 20 |
| | -08 | 4, 12, 22, 32, 42 | 47 |
| | -09 | 4, 12, 17 | 20 |
| | CB01-01 | 4, 12 | 22 |
| | -02 | 4, 12, 22 | 26 |
| | -03 | 4, 12, 22, 32 | 36 |
| | -04 | 4, 12, 22, 32 | 38 |
| | -05 | 4, 12, 22, 32, 37 | 41 |
| | -06 | 4, 12, 22, 29 | 32 |
| | -07 | 4, 12, 22, 27 | 29 |
| | -08 | 4, 14, 28 | 38 |
| | -09 | 4, 12, 22, 32, 42, 52, 62, 72 | 79 |
| | -10 | 4, 12, 17 | 19 |
| | CB02-01 | 4, 12, 22 | 25 |
| | -02 | 4, 12, 22, 27 | 31 |
| | -03 | 4, 12, 22, 32 | 36 |
| | -04 | 4, 12, 22, 32 | 37 |
| | -05 | 4, 12, 22, 32 | 38 |
| | -06 | 4, 12, 22, 32, 42 | 44 |
| | -07 | 4, 12, 22, 32, 42, 48 | 52 |
| | -08 | 4, 12, 22, 32, 42, 52, 58 | 62 |
| | -09 | 4, 12, 22, 30 | 32 |
| | -10 | 4, 12, 22, 27 | 31 |
| | CB03-01 | 4, 12, 22, 32, 39 | 44 |
| | -02 | 4, 12, 22, 32, 42, 52 | 58 |
| | -03 | 4, 12, 22, 32, 42, 52, 62, 72, 82 | 86 |
| | -04 | 4, 12, 22, 32, 42, 52, 62 | 72 |
| | -05 | 4, 12, 22, 32, 42, 52 | 60 |
| | -06 | 4, 12, 22, 32, 37 | 41 |
| | -07 | 4, 12, 22 | 25 |
| | -08 | 4, 12, 18 | 25 |
| | -09 | 4, 12, 22, 32, 42, 52 | 58 |
| | -10 | 4, 12, 22, 32, 42, 57 | 66 |
| | -11 | 4, 15 | 23 |

(Continued)

(Sheet 1 of 6)

Table A2 (Continued)

| Location | | | |
| --- | --- | --- | --- |
| Range | Station | Meter Depths, ft | Bottom Depth ft |
| Main Bay (Continued) | CB04-01 | 4, 12, 22, 32, | 36 |
| | -02 | 4, 12, 22, 32, 42 | 50 |
| | -03 | 4, 12, 22, 32, 42, 52, 62 | 64 |
| | -04 | 4, 12, 22, 32, 42, 52, 62, 72, 82, 92 | 96 |
| | -05 | 4, 12, 22, 32, 42, 52, 62, 72, 82, 92, 97 | 102 |
| | -06 | 4, 12, 22 | 24 |
| | -07 | 4, 12, 16 | 18 |
| | CB05-01 | 4, 12, 22, 27 | 29 |
| | -02 | 4, 12, 22, 32 | 36 |
| | -03 | 4, 12, 22, 32, 42 | 51 |
| | -04 | 4, 12, 22, 32, 42, 52, 62 | 65 |
| | -05 | 4, 12, 22, 32, 42, 52, 62, 72, 82, 92, 102, 112 | 115 |
| | -06 | 4, 12, 22 | 26 |
| | CB06-01 | 2, 12, 20 | 22 |
| | -02 | 2, 12, 18 | 20 |
| | -03 | 2, 12, 22, 32 | 34 |
| | -04 | 2, 12, 22, 32, 37 | 39 |
| | -05 | 2, 12, 29 | 21 |
| | CB07-01 | 4, 11 | 13 |
| | -02 | 2, 13 | 22 |
| | -03 | 2(4), 12, 22, 28 | 30 |
| | -04 | 2, 12, 22 | 24 |
| | -05 | 2, 12, 22, 32 | 35 |
| Potomac | PO01-01 | 2, 12, 22, 29 | 31 |
| | -02 | 2, 12, 22, 32, 37 | 39 |
| | -03 | 2, 12, 22, 32, 40 | 42 |
| | -04 | 2, 12, 22, 32, 42, 50 | 54 |
| | -05 | 2, 12, 22, 31 | 33 |
| | PO02-01 | 2, 12, 22, 30 | 33 |
| | -02 | 2, 12, 22, 32, 42, 52, 60 | 65 |
| | -03 | 2, 12, 22, 30 | 33 |
| | PO03-01 | 2, 12, 22, 32, 42, 52, 57 | 57 |
| | -02 | 2, 12, 22, 32, 36 | 38 |
| | PO04-01 | 2, 12, 22 | 27 |
| | -02 | 2, 12, 22, 42 | 45 |
| | PO05-01 | 2, 12 | 15 |
| | -02 | 2, 10, 19 | 22 |
| | -03 | 2, 10, 19 | 22 |

(Continued)

Table A2 (Continued)

| Location: Range | Location: Station | Meter Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Potomac (Continued) | P006-01 | 2, 12, 22, 32, 42, 52, 62, 72 | 74 |
| | P007-01 | 2, 12 | 15 |
| | -02 | 2, 12, 21 | 25 |
| | P008-01 | 6 | -- |
| | -02 | 4, 10, 18 | 20 |
| | P009-01 | 2, 13 | 15 |
| | -02 | 2, 11, 21 | 23 |
| | P010-01 | 2, 12, 22, 28 | 30 |
| | -02 | 2, 12, 22 | 24 |
| | P011-01 | 2, 12, 22, 32 | 35 |
| | P012-01 | 2, 12, [illegible], 32, 42, 52 | 61 |
| | P013-01 | 2, 12, [illegible] | 28 |
| (1971/1973) | | | |
| James | J01-01 | 3, [illegible], 14 | 15/19 |
| | -02 | 2, [illegible], [illegible], 42/5, 15, 25, 35, 45 | 52/51 |
| | -03 | [illegible], [illegible], 36.5, 56.5, 66.5, 76.5, 86.5, 4, 14, 24, 34, 44, 54, 64, 74 | 87/79 |
| | J02-01 | 7/4, 12 | 11/14 |
| | -02 | 2, 12/5, 15, 25 | 25/27 |
| | -03 | 5, 15, 25, 35, 45, 49/5, 15, 25, 35, 45 | 50/51 |
| | J03-01 | 3, 12, 20/3, 13, 19 | 22/25 |
| | -02 | 2, 7/3, 12, 18 | 18/21 |
| | J04-01 | 2, 9, 15 | 18 |
| | -02 | 2, 12, 19 | 20 |
| | J05-01 | 2, 11, 21 | 23 |
| | -02 | 3, 13, 23, 33, 47 | 48 |
| | J06-01 | 3, 13, 23, 29 | 32 |
| | J07-01 | 3, 13, 23, 28 | 30 |
| | J08-01 | 5, 15, 25 | 28 |
| York | Y01-01 | 3, 13, 23, 33 | 35 |
| | -02 | 5, 15, 25, 35, 45, 54 | 55 |
| | Y02-01 | 4, 14, 24, 34, 44, 54, 64, 70 | 72 |
| | Y03-01 | 2, 9, 13 | 17 |
| | -02 | 3, 13, 23, 33 | 35 |
| | Y04-01 | 2, 12 | 15 |
| | -02 | 3, 13, 23, 33 | 32 |
| | Y05-01 | 4, 14, 23, 26 | 28 |
| | Y06-01 | 4, 14, 24 | 27 |
| | Y07-01 | 4, 12.5, 17.5 | 20 |
| | -02 | 4, 14 | 16 |

(Continued)

(Sheet 3 of 6)

Table A2 (Continued)

| Location Range | Station | Meter Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Rappahannock | R01-01 | 2, 12, 22 | 29 |
| | -02 | 2, 12, 22, 32 | 35 |
| | R02-01 | 2, 13, 23 | 30 |
| | -02 | 2, 12, 22, 32, 42, 52 | 56 |
| | R03-01 | 2, 12, 22, 32, 42, 52 | 62 |
| | -02 | 2, 13 | 18 |
| | R04-01 | 2, 12, 20 | 23 |
| | -02 | 2, 12, 22, 32 | 37 |
| | R05-01 | 2, 12, 22 | 26 |
| | R06-01 | 2, 12, 16.5 | 18 |
| | R07-01 | 2, 12 | 18 |
| | R08-01 | 2, 12, 22 | 26 |
| | R09-01 | 2, 12 | 15 |
| | R10-01 | 2, 12, 22 | 25 |
| Patuxent | P01-01 | 4, 12, 22, 32, 40 | 44 |
| | -02 | 4, 12, 22, 32, 42, 52 | 56 |
| | P02-01 | 4, 12, 22 | 26 |
| | -02 | 4, 12, 22, 32, 42, 52, 62, 72 | 80 |
| | P03-01 | 4, 12, 22 | 28 |
| | P04-01 | 4, 12, 22, 32 | 38 |
| | -02 | 4, 12 | -- |
| | P05-01 | 4, 12 | 15 |
| | -02 | 4, 12, 16 | 20 |
| | P06-01 | 4, 12, 22 | 26 |
| | P07-01 | 6 | 10 |
| South River | S01-01 | 4, 12, 17 | 20 |
| | S02-01 | 4, 12 | 14 |
| Severn | SE01-01 | 4, 12, 18 | 20 |
| | SE02-01 | 4, 12, 18 | 20 |
| | -02 | 4, 12, 22 | 24 |
| Magothy | MA01-01 | 4, 12, 18 | 21 |
| | MA02-01 | 4, 15 | 18 |
| Patapsco | PR01-01 | 2, 14 | 16 |
| | -02 | 2, 13 | 18 |
| | -03 | 2, 12, 22, 32, 38 | 42 |

(Continued)

Table A2 (Continued)

| Location Range | Location Station | Meter Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Patapsco (Continued) | PR02-01 | 2, 14 | 18 |
| | -02 | 2, 12, 22, 32, 39 | 41 |
| | PR03-01 | 2, 12, 22, 32, 39 | 41 |
| | -02 | 2, 12, 22 | 24 |
| Back River North | BN01-01 | 4 | 8 |
| Middle | MR01-01 | 4, 8 | 10 |
| Gunpowder | GR01-01 | 2, 12, 20 | 22 |
| Bush | BR01-01 | 4, 8 | 12 |
| Susquehanna | SU01-01 | 4, 14 | 16 |
| | -02 | 4, 12, 22, 26 | 28 |
| Northeast | NE01-01 | 4, 11 | 13 |
| | NE02-01 | 4 | 7 |
| Elk | E01-01 | 4, 12, 18 | 21 |
| | E02-01 | 4, 8 | 10 |
| Bohemia | BO01-01 | 4 | 7 |
| Sassafras | SA01-01 | 4, 14 | 15 |
| | SA02-01 | 4, 12, 22, 32, 37 | 38 |
| Chester | CH01-01 | 4, 12, 22, 32, 42, 52 | 55 |
| | CH02-01 | 4, 12, 25 | 28 |
| | -02 | 4, 14, 26 | 30 |
| | CH03-01 | 4, 11 | 18 |
| | CH04-01 | 4, 12, 22, 32, 44 | 49 |
| Wye | W01-01 | 4, 12, 22, 32, 42, 51 | 55 |
| | W02-01 | 4, 12, 21 | 23 |
| | W03-01 | 4, 12 | 14 |
| Miles | MI01-01 | 4, 12, 22, 32 | 38 |
| | MI02-01 | 4, 10 | 12 |

(Continued)

Table A2 (Concluded)

| Location: Range | Location: Station | Meter Depths (ft) | Bottom Depth ft |
|---|---|---|---|
| Tred Avon | TA01-01 | 4, 12, 23 | 26 |
| | TA02-01 | 4, 14 | 20 |
| Choptank | C01-01 | 4, 12, 22, 32, 42, 52, 62 | 70 |
| | C02-01 | 4, 12, 22, 27 | 31 |
| | C03-01 | 4, 11 | 15 |
| Little Choptank | LC01-01 | 4, 12, 22 | 30 |
| | LC02-01 | 4, 12, 22, 27 | 29 |
| Nanticoke | N01-01 | 4, 12, 24 | 27 |
| | N02-01 | 4, 12 | 14 |
| | N03-01 | 4, 12 | 14 |
| Wicomico | WI01-01 | 4, 11 | 13 |
| Manokin | MN01-01 | 4 | 9 |
| Big Annemessex | A01-01 | 4, 12 | 19 |
| Pocomoke South | PS01-01 | 4 | 6 |
| Back River South | B01-01 | 2, 12 | 15 |
| Poquoson | PQ01-01 | 4, 12 | 15 |
| Mobjack Bay | MB01-01 | 2, 12 | 13 |
| | -02 | 2, 12 | 17 |
| | -03 | 3.5, 13.5, 17.5 | 18 |
| | MB02-01 | 2, 12, 15 | 18 |
| | MB03-01 | 6, 16, 24 | 25 |
| | MB04-01 | 2, 12, 19.5 | 23 |
| | MB05-01 | 2, 12, 19 | 20 |
| Piankatank | PI01-01 | 4, 12, 20 | 25 |
| | PI02-01 | 4, 14, 24 | 33 |
| Great Wicomico | G01-01 | 4, 14, 17 | 20 |
| | G02-01 | 4, 14, 17 | 20 |

(Sheet 6 of 6)

Table A3

Salinity Stations and Depths

| Location: Range | Location: Station | Sampling Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Main Bay | CB00-01 | 4, 12, 22, 32 | 36 |
| | -02 | 4, 12, 22, 32, 42, 52, 62, 68 | 75 |
| | -03 | 4, 12, 22, 32, 38 | 41 |
| | -04 | 4, 12, 22, 30 | 33 |
| | -05 | 4, 12, 17 | 20 |
| | -06 | 4, 12 | 15 |
| | -07 | 4, 12, 18 | 20 |
| | -08 | 4, 12, 22, 32, 42 | 47 |
| | -09 | 4, 12, 17 | 20 |
| | CB01-01 | 4, 12 | 22 |
| | -02 | 4, 12, 22 | 26 |
| | -03 | 4, 12, 22, 32 | 36 |
| | -04 | 4, 12, 22, 32 | 38 |
| | -05 | 4, 12, 22, 32, 37 | 41 |
| | -06 | 4, 12, 22, 29 | 32 |
| | -07 | 4, 12, 22, 27 | 29 |
| | -08 | 4, 14, 28 | 38 |
| | -09 | 4, 12, 22, 32, 42, 52, 62, 72 | 79 |
| | -10 | 4, 12, 17 | 19 |
| | CB02-01 | 4, 12, 22 | 25 |
| | -02 | 4, 12, 22, 27 | 31 |
| | -03 | 4, 12, 22, 32 | 36 |
| | -04 | 4, 12, 22, 32 | 37 |
| | -05 | 4, 12, 22, 32 | 38 |
| | -06 | 4, 12, 22, 32, 42 | 44 |
| | -07 | 4, 12, 22, 32, 42, 48 | 52 |
| | -08 | 4, 12, 22, 32, 42, 52, 58 | 62 |
| | -09 | 4, 12, 22, 30 | 32 |
| | -10 | 4, 12, 22, 27 | 31 |
| | CB03-01 | 4, 12, 22, 32, 39 | 44 |
| | -02 | 4, 12, 22, 32, 42, 52 | 58 |
| | -03 | 4, 12, 22, 32, 42, 52, 62, 72, 82 | 86 |
| | -04 | 4, 12, 22, 32, 42, 52, 62 | 72 |
| | -05 | 4, 12, 22, 32, 42, 52 | 60 |
| | -06 | 4, 12, 22, 32, 37 | 41 |
| | -07 | 4, 12, 22 | 25 |
| | -08 | 4, 12, 18 | 25 |
| | -09 | 4, 12, 22, 32, 42, 52 | 58 |
| | -10 | 4, 12, 22, 32, 42, 57 | 66 |
| | -11 | 4, 15 | 23 |

(Continued)

Table A3 (Continued)

| Location: Range | Location: Station | Sampling Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Main Bay (Continued) | CB04-01 | 4, 12, 22, 32 | 36 |
| | -02 | 4, 12, 22, 32, 42 | 50 |
| | -03 | 4, 12, 22, 32, 42, 52, 62 | 64 |
| | -04 | 4, 12, 22, 32, 42, 52, 62, 72, 82, 92 | 96 |
| | -05 | 4, 12, 22, 32, 42, 52, 62, 72, 82, 92, 97 | 102 |
| | -06 | 4, 12, 22 | 24 |
| | -07 | 4, 12, 16 | 18 |
| | CB05-01 | 4, 12, 22, 27 | 29 |
| | -02 | 4, 12, 22, 32 | 36 |
| | -03 | 4, 12, 22, 32, 42 | 51 |
| | -04 | 4, 12, 22, 32, 42, 52, 62 | 65 |
| | -05 | 4, 12, 22, 32, 42, 52, 62, 72, 82, 92, 102, 112 | 115 |
| | -06 | 4, 12, 22 | 26 |
| | CB06-01 | 2, 12, 20 | 22 |
| | -02 | 2, 12, 18 | 20 |
| | -03 | 2, 12, 22, 32 | 34 |
| | -04 | 2, 12, 22, 32, 37 | 39 |
| | -05 | 2, 12, 19 | 21 |
| | CB07-01 | 5, 10 | 13 |
| | -02 | 2, 12, 22, 26 | 22 |
| | -03 | 2, 12, 22, 29 | 30 |
| | -04 | 2, 12, 22, 25 | 24 |
| | -05 | 2, 12, 22, 32, 38 | 35 |
| Potomac | PO01-01 | 2, 12, 22, 29 | 31 |
| | -02 | 2, 12, 22, 32, 37 | 39 |
| | -03 | 2, 12, 22, 32, 40 | 42 |
| | -04 | 2, 12, 22, 32, 42, 50 | 54 |
| | -05 | 2, 12, 22, 31 | 33 |
| | PO02-01 | 2, 12, 22, 30 | 33 |
| | -02 | 2, 12, 22, 32, 42, 52, 60 | 65 |
| | -03 | 2, 12, 22, 30 | 33 |
| | PO03-01 | 2, 12, 22, 32, 42, 52, 57 | 57 |
| | -02 | 2, 12, 22, 32, 36 | 38 |
| | PO04-01 | 2, 12, 22 | 27 |
| | -02 | 2, 12, 22, 42 | 45 |
| | PO05-01 | 2, 12 | 15 |
| | -02 | 2, 10, 19 | 22 |
| | -03 | 2, 10, 19 | 22 |

(Continued)

Table A3 (Continued)

| Location | | | Bottom |
|---|---|---|---|
| Range | Station | Sampling Depths, ft | Depth ft |
| Potomac | P006-01 | 2, 12, 22, 32, 42, 52, 62, 72 | 74 |
| (Continued) | P007-01 | 2, 12 | 15 |
| | -02 | 2, 12, 21 | 25 |
| | P008-01 | 6 | -- |
| | -02 | 2, 12, 22 | 20 |
| | P009-01 | 2, 13 | 15 |
| | -02 | 2, 11, 21 | 23 |
| | P010-01 | 2, 12, 22, 28 | 30 |
| | -02 | 2, 12, 22 | 24 |
| | P011-01 | 2, 12, 22, 32 | 35 |
| | P012-01 | 2, 12, 22, 32, 42, 52 | 61 |
| | P013-01 | 2, 12, 25 | 28 |
| (1971/1973) | | | |
| James | J01-01 | 0, 8, 16/4, 14 | 15/19 |
| | -02 | 0, 26, 33, 52, 59, 66/5, 15, 25, 35, 45 | 52/51 |
| | -03 | 0, 46, 52, 92, 98/4, 14, 24, 34, 44, 54, 64, 74 | 87/79 |
| | J02-01 | 0, 7, 13/4, 12 | 11/14 |
| | -02 | 0, 7, 13, 20, 26/5, 15, 25 | 25/27 |
| | -03 | 0, 7, 13, 20, 26, 33, 39, 46, 52/5, 15, 25, 35, 45 | 50/51 |
| | J03-01 | 0, 7, 13, 20, 26/3, 13, 19 | 22/25 |
| | -02 | 0, 7, 13, 20/3, 12, 18 | 18/21 |
| | J04-01 | 0, 7, 13, 20 | 18 |
| | -02 | 0, 7, 13, 20, 26 | 20 |
| | J05-01 | 0, 7, 13, 20, 26 | 23 |
| | -02 | 0, 7, 13, 20, 26, 33, 39, 46, 52 | 48 |
| York | Y01-01 | 3, 13, 23, 33 | 35 |
| | -02 | 5, 15, 25, 35, 45, 54 | 55 |
| | Y02-01 | 4, 14, 24, 34, 44, 54, 64, 70 | 72 |
| | Y03-01 | 2, 9, 13 | 17 |
| | -02 | 3, 13, 23, 33 | 35 |
| | Y04-01 | 2, 12 | 15 |
| | -02 | 3, 13, 23, 33 | 32 |
| | Y05-01 | 4, 14, 23, 26 | 28 |
| | Y06-01 | 4, 14, 24 | 27 |
| | Y07-01 | 4, 12.5, 17.5 | 20 |
| | -02 | 4, 14 | 16 |

(Continued)

Table A3 (Continued)

| Location Range | Station | Sampling Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Rappahannock | R01-01 | 7, 13, 20, 26 | 29 |
| | -02 | 7, 13, 20, 26, 33 | 35 |
| | R02-01 | 7, 13, 20, 26 | 30 |
| | -02 | 7, 13, 20, 26, 33, 39, 46, 52 | 56 |
| | R03-01 | 7, 13, 20, 26, 33, 39, 46, 52, 59 | 62 |
| | -02 | 7, 13 | 18 |
| | R04-01 | 7, 13, 20 | 23 |
| | -02 | 7, 13, 20, 26, 33 | 37 |
| | R05-01 | 7, 13, 20, 26 | 26 |
| | R06-01 | 7, 13 | 18 |
| | R07-01 | 7, 13 | 18 |
| | R08-01 | 7, 13, 20, 26 | 26 |
| | R09-01 | 7, 13 | 15 |
| | R10-01 | 7, 13, 20 | 25 |
| Patuxent | P01-01 | 4, 12, 22, 32, 40 | 44 |
| | -02 | 4, 12, 22, 32, 42, 52 | 56 |
| | P02-01 | 4, 12, 22 | 26 |
| | -02 | 4, 12, 22, 32, 42, 52, 62, 72 | 80 |
| | P03-01 | 4, 12, 22 | 28 |
| | P04-01 | 4, 12, 22, 32 | 38 |
| | -02 | 4, 12 | -- |
| | P05-01 | 4, 12 | 15 |
| | -02 | 4, 12, 16 | 20 |
| | P06-01 | 4, 12, 22 | 26 |
| | P07-01 | 6 | 10 |
| South River | S01-01 | 4, 12, 18, 25 | 20 |
| | S02-01 | 4, 12, 17 | 14 |
| Severn | SE01-01 | 4, 12, 18 | 20 |
| | SE02-01 | 4, 12, 18, 21 | 20 |
| Magothy | MA01-01 | 4, 12, 18 | 21 |
| | MA02-01 | 4, 15 | 18 |
| Patapsco | PR01-01 | 2, 14 | 16 |
| | -02 | 2, 14 | 18 |
| | -03 | 2, 12, 22, 32, 38 | 42 |

(Continued)

Table A3 (Continued)

| Location: Range | Location: Station | Sampling Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Patapsco (Continued) | PR02-01 | 2, 14 | 18 |
| | -02 | 2, 14 | 41 |
| | PR03-01 | 2, 12, 22, 32, 39 | 41 |
| | -02 | 2, 12, 22 | 24 |
| Back River North | BN01-01 | 4 | 8 |
| Middle | MR01-01 | 2, 12 | 10 |
| Gunpowder | GR01-01 | 2, 12, 22 | 22 |
| Bush | BR01-01 | 5, 10 | 12 |
| Northeast | NE01-01 | 4, 11 | 13 |
| | NE02-01 | 4 | 7 |
| Elk | E01-01 | 4, 12, 18, 21 | 21 |
| | E02-01 | 4, 8 | 10 |
| Bohemia | BO01-01 | 4 | 7 |
| Sassafras | SA01-01 | 4, 14 | 15 |
| | SA02-01 | 4, 12, 22, 32, 37 | 38 |
| Chester | CH01-01 | 4, 12, 22, 32, 42, 52 | 55 |
| | CH02-01 | 4, 12, 25 | 28 |
| | -02 | 4, 12, 26 | 30 |
| | CH03-01 | 4, 11 | 18 |
| | CH04-01 | 4, 12, 22, 32, 44 | 49 |
| Wye | W01-01 | 4, 12, 22, 32, 42, 51 | 55 |
| | W02-01 | 4, 12, 21 | 23 |
| | W03-01 | 4, 12 | 14 |
| Miles | MI01-01 | 4, 12, 22, 32 | 38 |
| | MI02-01 | 4, 10 | 12 |
| Tred Avon | TA01-01 | 4, 12, 23 | 26 |
| | TA02-01 | 4, 14 | 20 |

(Continued)

Table A3 (Concluded)

| Location: Range | Location: Station | Sampling Depths, ft | Bottom Depth ft |
|---|---|---|---|
| Choptank | C01-01 | 4, 12, 22, 32, 42, 52, 62 | 70 |
| | C02-01 | 4, 12, 22, 27 | 31 |
| | C03-01 | 4, 11 | 15 |
| Little Choptank | LC01-01 | 4, 12, 22 | 30 |
| | LC02-01 | 4, 12, 22, 27 | 29 |
| Nanticoke | N01-01 | 4, 12, 24 | 27 |
| | N02-01 | 4, 12 | 14 |
| | N03-01 | 4, 12 | 14 |
| Wicomico | WI01-01 | 4, 11 | 13 |
| Manokin | MN01-01 | 4 | 9 |
| Big Annemessex | A01-01 | 4, 12 | 19 |
| Pocomoke South | PS01-01 | 4 | 6 |
| Back River South | B01-01 | 2, 12 | 15 |
| Poquoson | PQ01-01 | 4, 12 | 15 |
| Mobjack Bay | MB01-01 | 7, 13 | 13 |
| | -02 | 7, 13 | 17 |
| | -03 | 7, 13 | 18 |
| | MB02-01 | 7, 13 | 18 |
| | MB03-01 | 7, 13, 20 | 25 |
| | MB04-01 | 7, 13, 20 | 23 |
| | MB05-01 | 7, 13, 20 | 20 |
| Piankatank | PI01-01 | 4, 12, 20 | 25 |
| | PI02-01 | 4, 14, 24 | 33 |
| Great Wicomico | G01-01 | 4, 14, 17 | 20 |
| | G02-01 | 4, 14, 17 | 20 |

Table A4

Slack-Water Stations

| Station | Months Occupied |
|---|---|
| | **Chesapeake Bay** |
| 657 W | Monthly from Oct 1969 to Oct 1973 |
| 707 O | |
| 724 R | |
| 745 A | |
| 805 C | |
| 819 O | |
| 834 G | |
| 848 E | |
| 857 C | |
| 909 | |
| 919 T | |
| E 00 | |
| | **Potomac River** |
| 752 R | Monthly from Nov 1970 to Nov 1971 |
| 752 P | |
| 752 | |
| 752 D | |
| PS-1 | |
| PS-2 | |
| PS-3 | |
| PS-4 | |
| P-8 | |
| P-16 | |
| P-22 | |
| P-29 | |
| P-35 | |

(Continued)

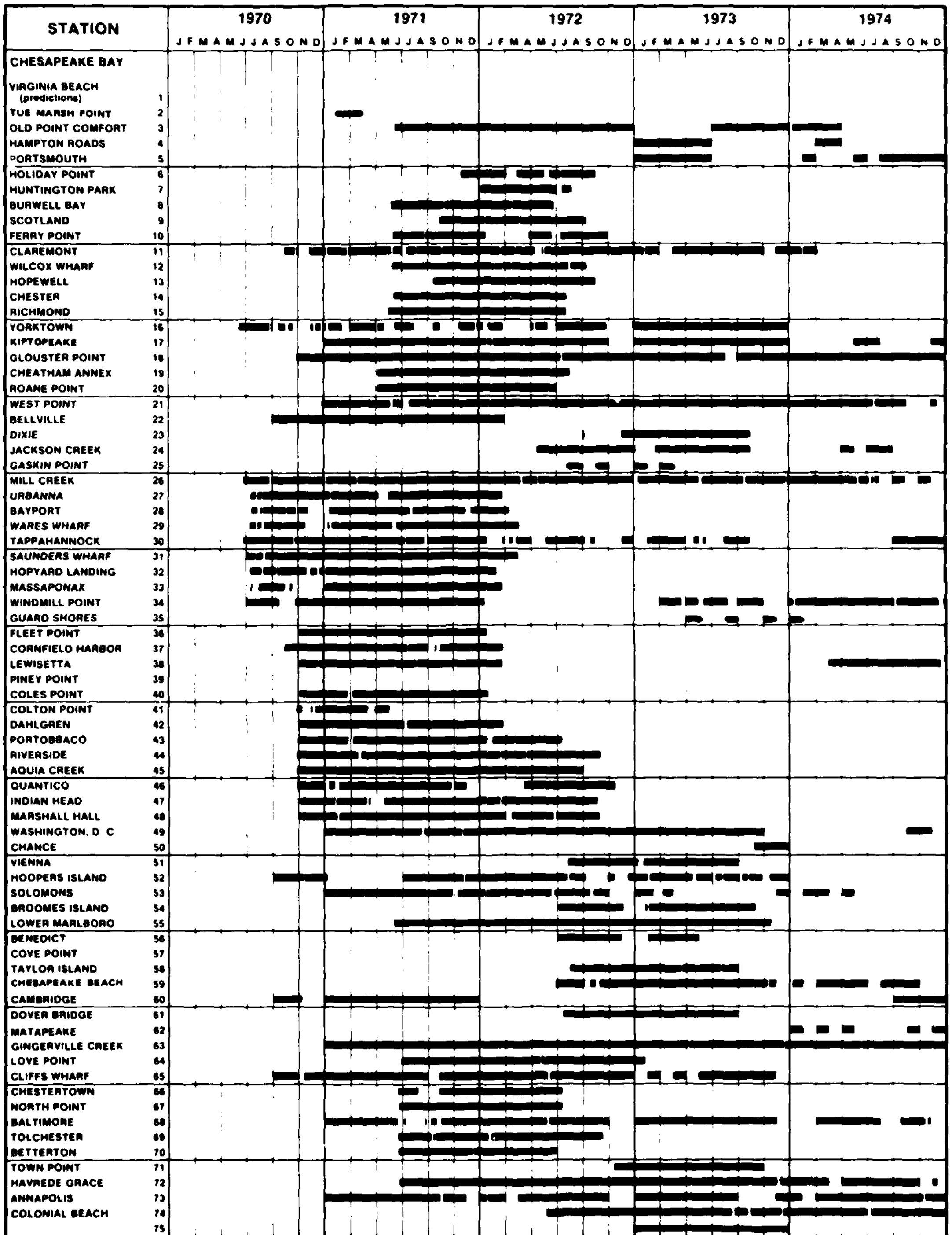
Table A4 (Continued)

| Station | Months Occupied |
| --- | --- |
| | **Potomac River (Continued)** |
| P-40 | Monthly from Nov 1970 to Nov 1971 |
| P-46 | ↓ |
| P-52 | ↓ |
| P-60 | ↓ |
| | **James River** |
| J-1 | June, Sep, Oct, Dec 1971; Apr 1972 |
| J-2 | Same as J-1 for 1971; Jan, Apr 1972 |
| J-3 | Same as J-1 for 1971; Jan, Mar, Apr, May 1972 |
| J-4 | Same as J-1 for 1971; Jan, Mar, Apr, May 1972 |
| J-5 | Same as J-1 for 1971; Jan, Mar, Apr 1972 |
| J-6 | Same as J-1 for 1971; Jan, Mar, Apr 1972 |
| J-7 | Same as J-6 |
| J-8 | Same as J-6 |
| | **York River** |
| Y-1 | Dec 1972; Jan, Feb, Mar, Apr, May, Jul, Aug, Sep, Oct, Nov 1973 |
| Y-2 | Every month from Dec 1972 to Nov 1973 |
| Y-3 | ↓ |
| Y-4 | ↓ |
| Y-5 | ↓ |
| Y-6 | ↓ |
| Y-7 | ↓ |
| | **Rappahannock River** |
| R00.0 | Aug, Oct, Dec 1970; Feb, Mar, Apr, May, Jul, Aug, Sep, Oct 1971 |
| R05.3 | Aug, Oct, Dec 1970; Feb, Mar, Apr, May, Aug, Sep 1971 |

(Continued)

Table A4 (Concluded)

| Station | Months Occupied |
|---|---|
| | Rappahannock River (Continued) |
| R09.3 | Same as R00.0 |
| R16.4 | Aug, Oct, Dec 1970; Feb, Mar, Apr, May, Jul, Sep, Oct 1971 |
| R21.5 | Same as R00.0 |
| R27.0 | Same as R00.0 |
| R32.1 | Same as R00.0 |
| R35.7 | Aug, Oct, Dec 1970; Feb, Mar, Apr, May, Aug, Sep, Oct 1971 |
| R40.4 | Same as R05.3 |
| R45.0 | Same as R00.0 |
| R47.3 | Aug, Dec 1970; Feb, Aug, Sep, Oct 1971 |
| R50.0 | Aug, Oct 1970; Apr 1971 |
| R52.0 | Aug, Oct 1970; Apr 1971 |




**PROTOTYPE TIDAL HEIGHTS COLLECTED FOR MODEL VERIFICATION**

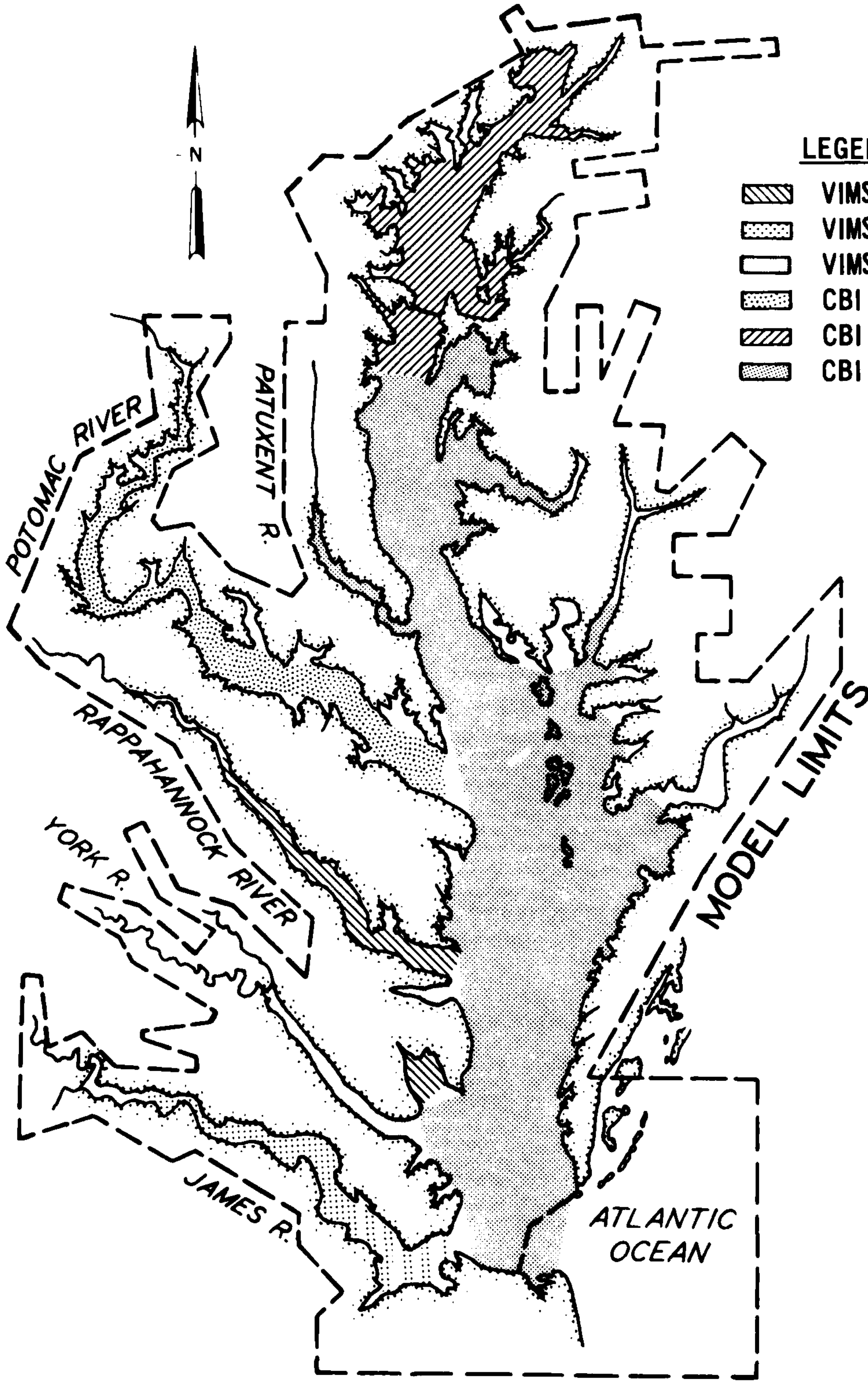



Plate A2. Velocity and salinity data collection report coverage areas

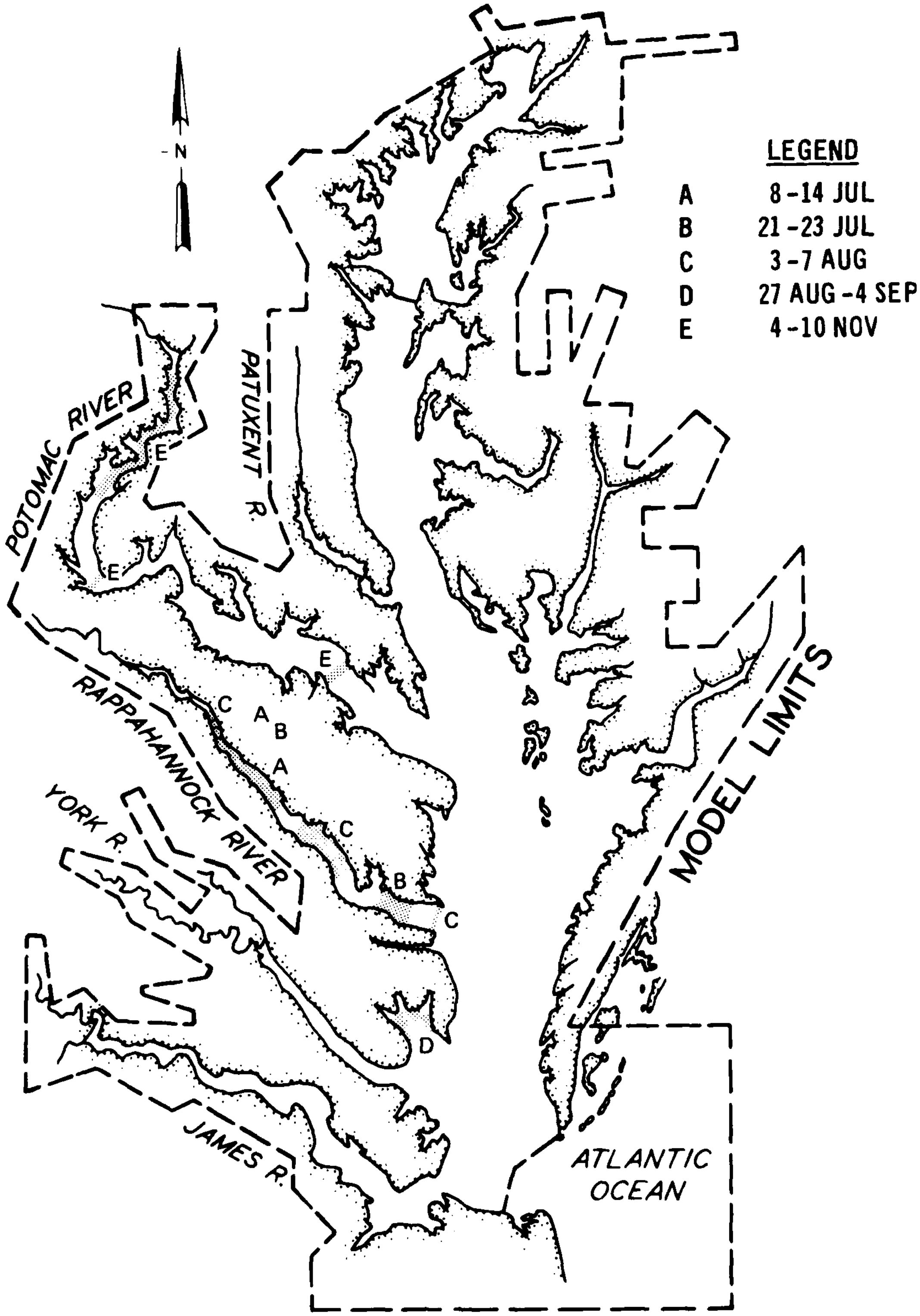



Plate A3. Velocity and salinity stations occupied in 1970

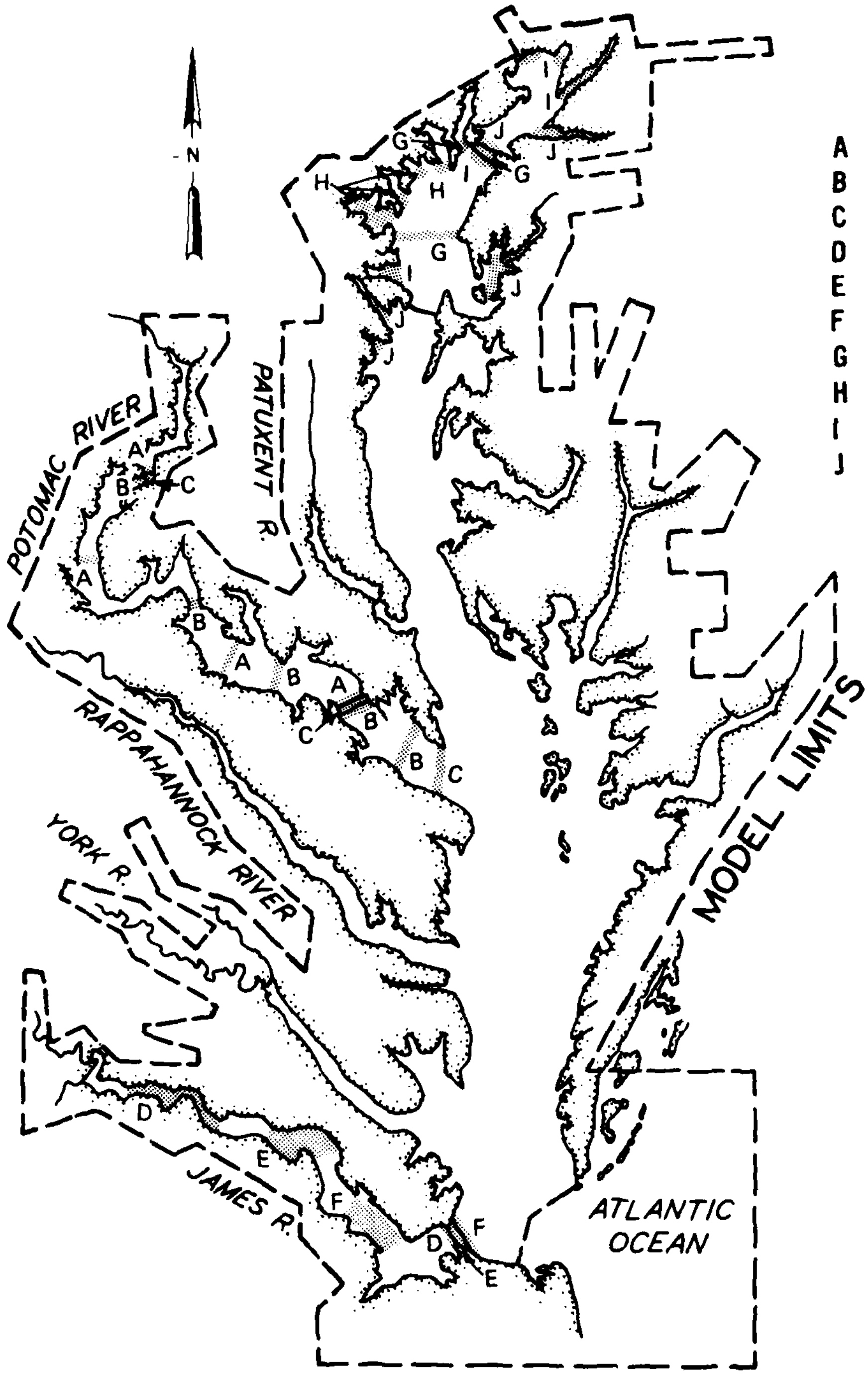



Plate A4. Velocity and salinity stations occupied in 1971

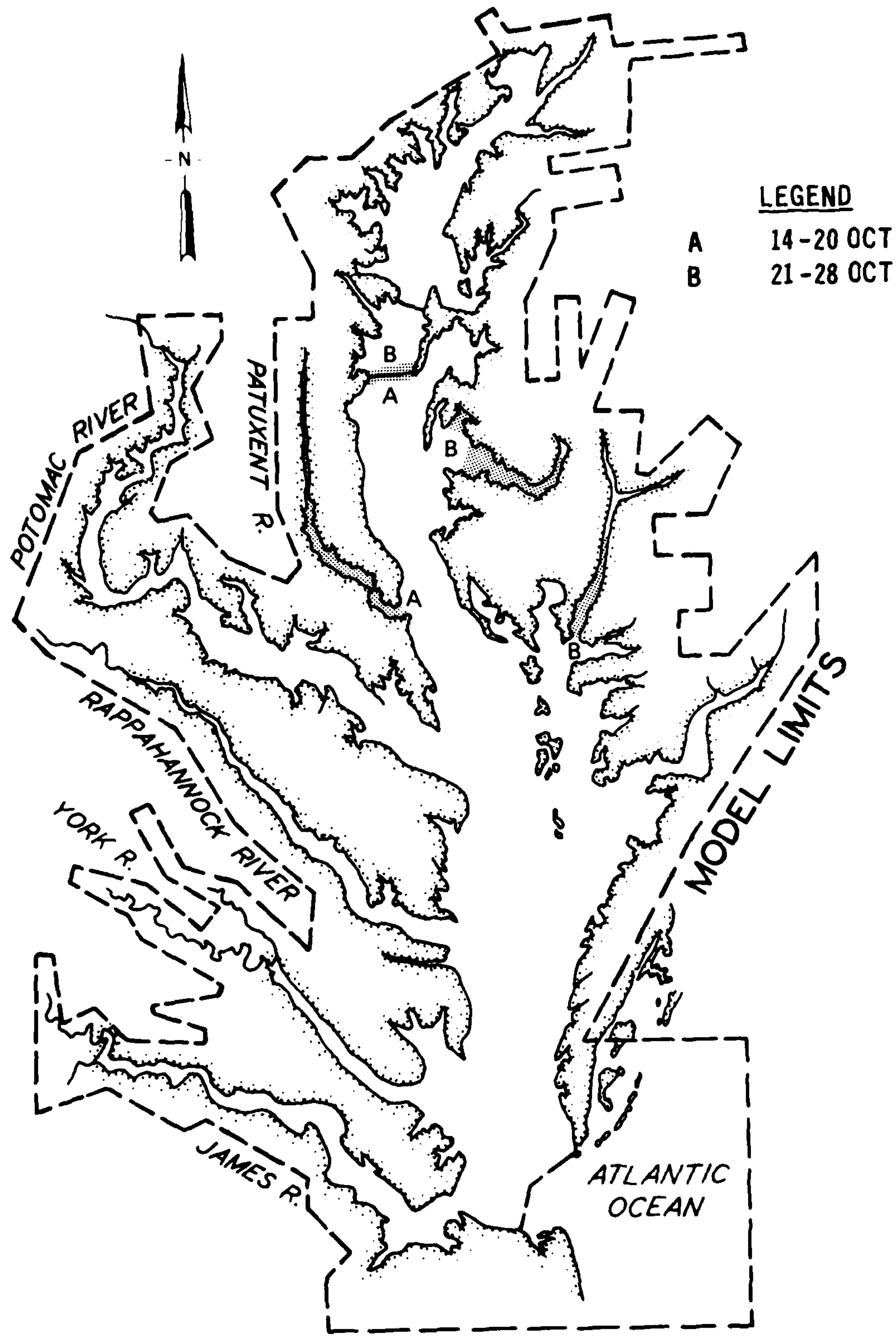



Plate A5. Velocity and salinity stations occupied in 1972

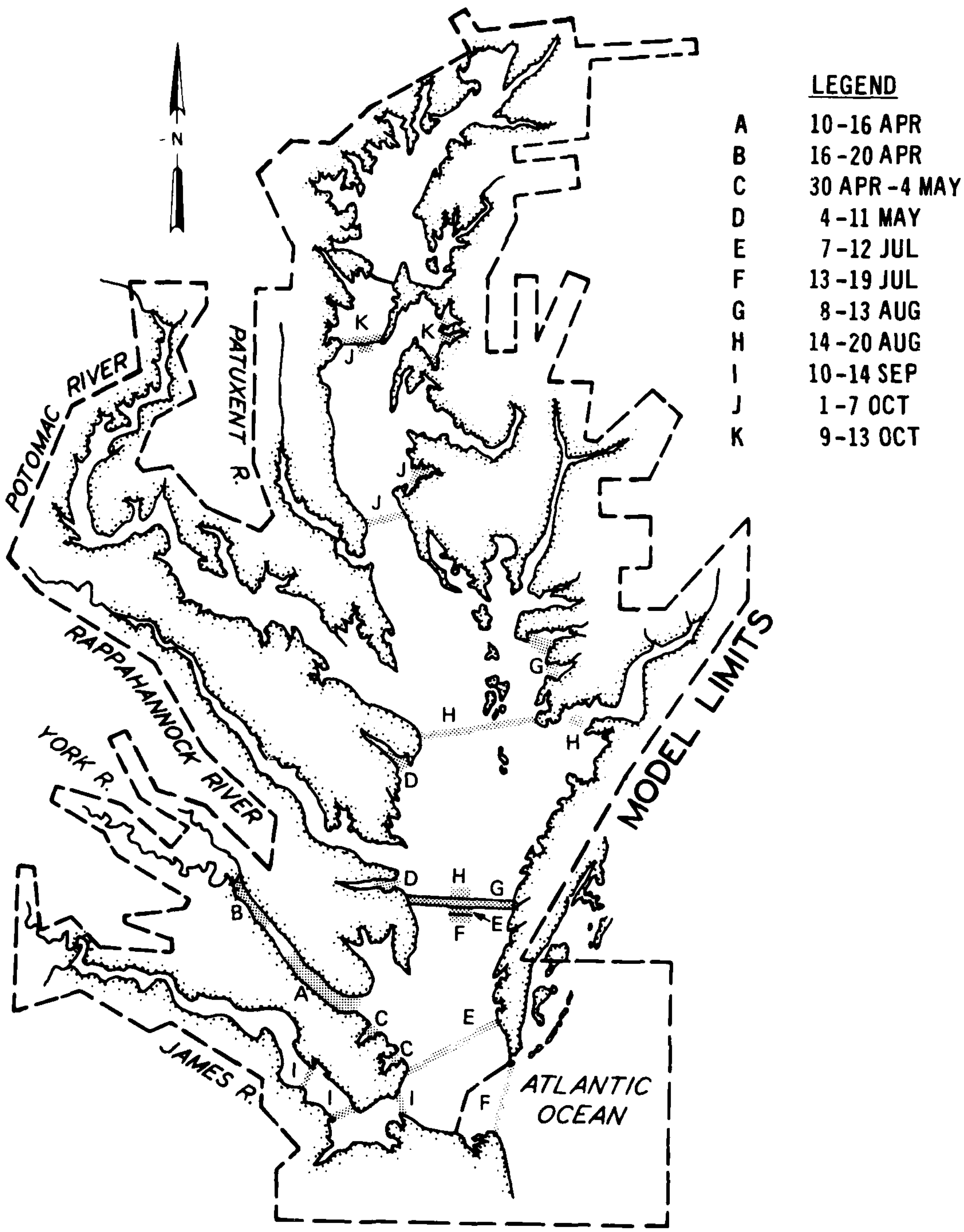



Plate A6. Velocity and salinity stations occupied in 1973

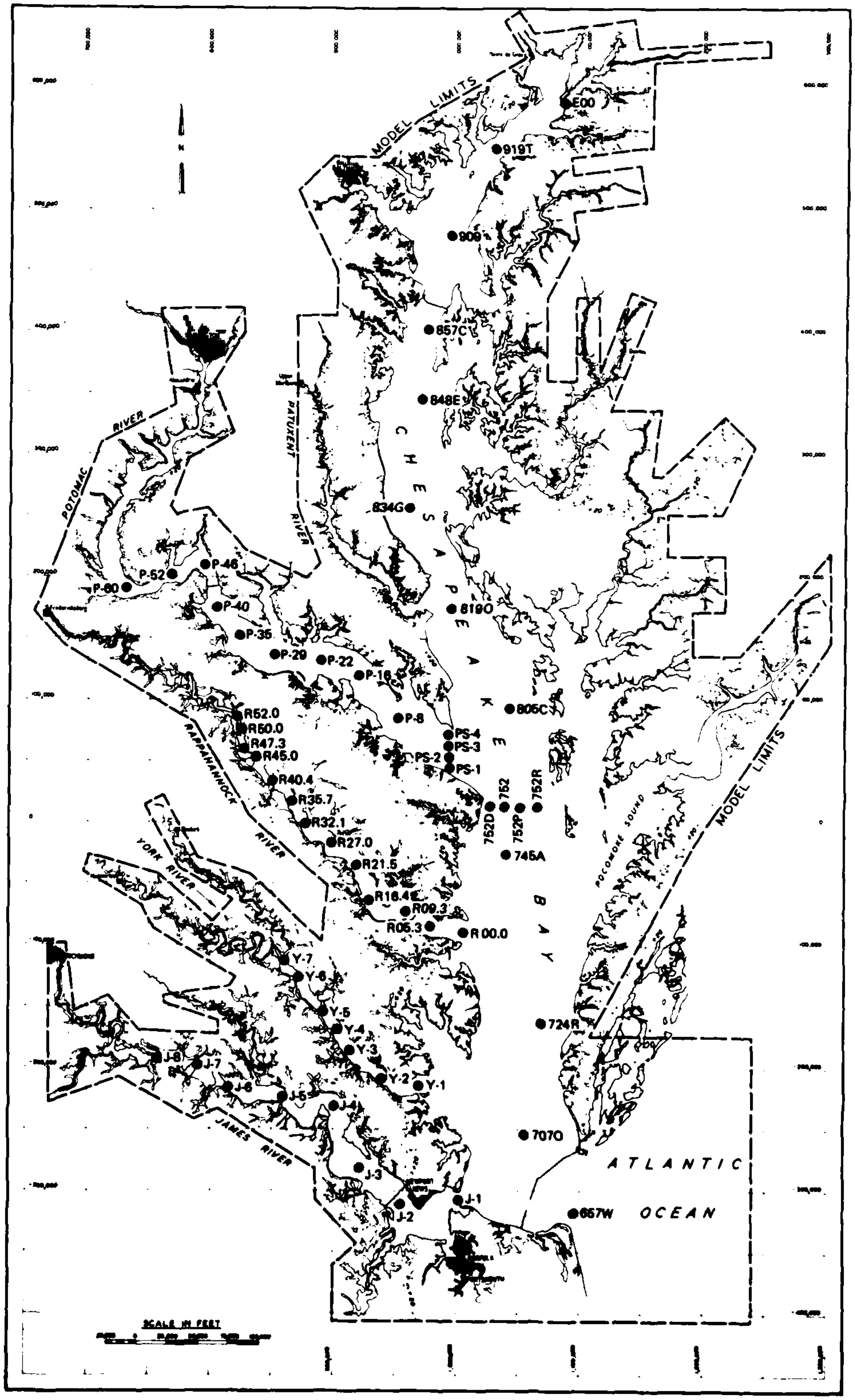
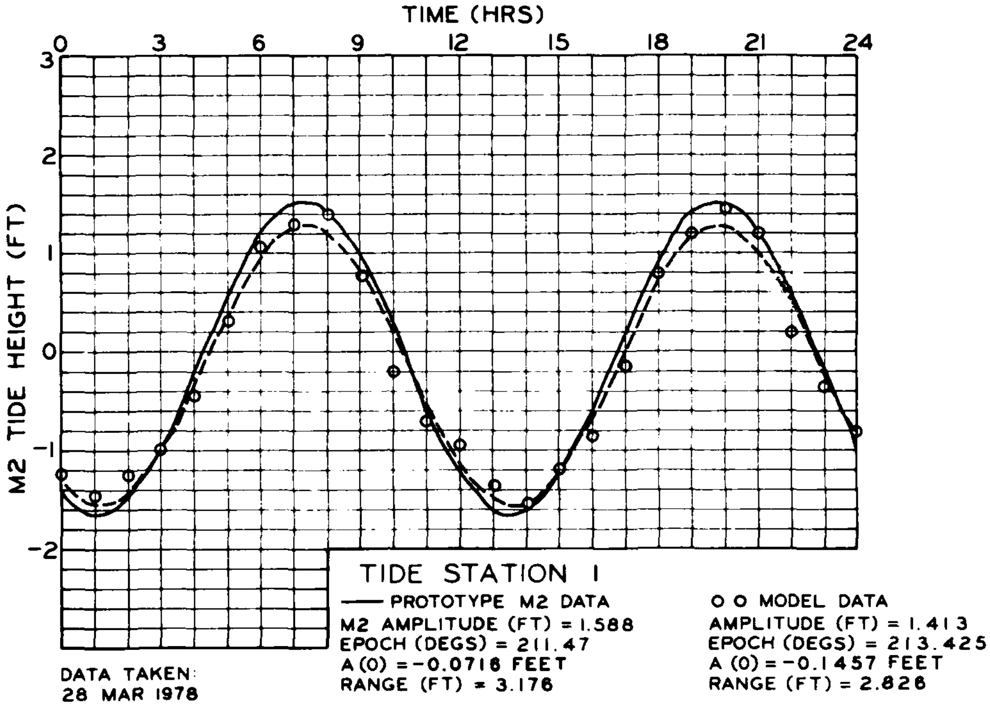



Plate A7. Same slack salinity stations

# APPENDIX B

## TIDAL VERIFICATION DATA

Comparison of Model and Prototype Tides for the
$M_2$ Constituent at Selected Tide Stations



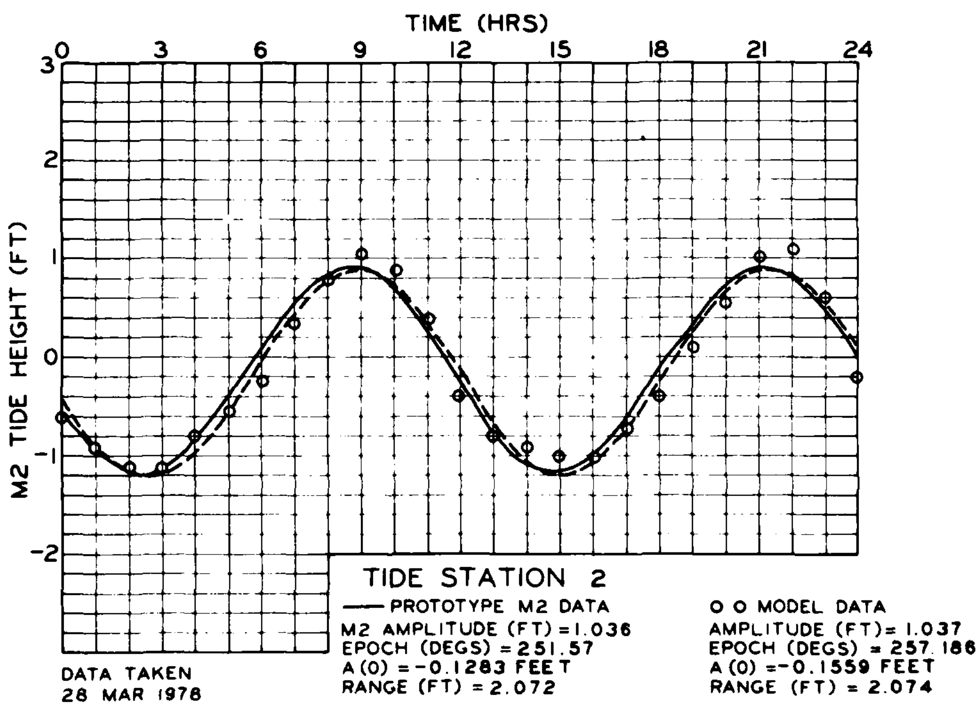
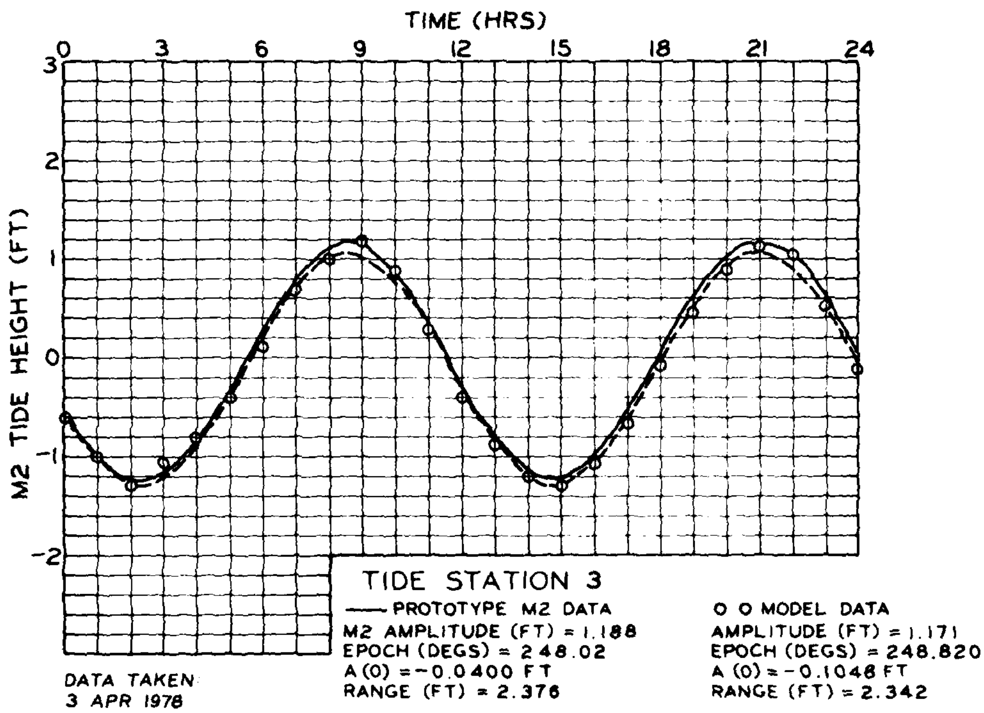




Plate B1. Model/prototype tide height comparison, sta 1 and 2



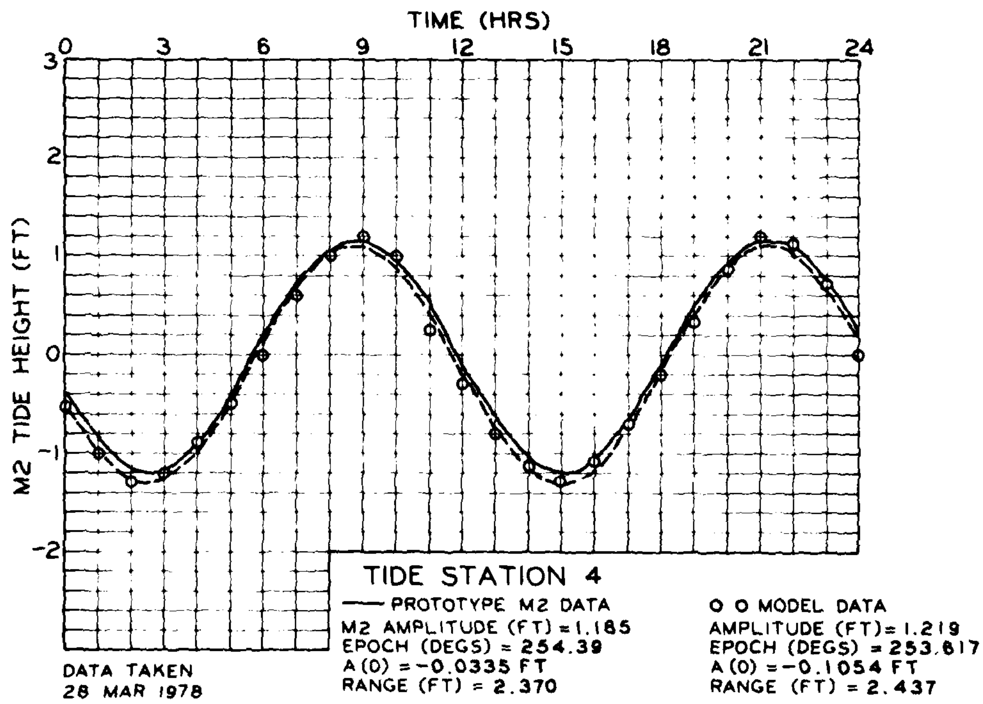
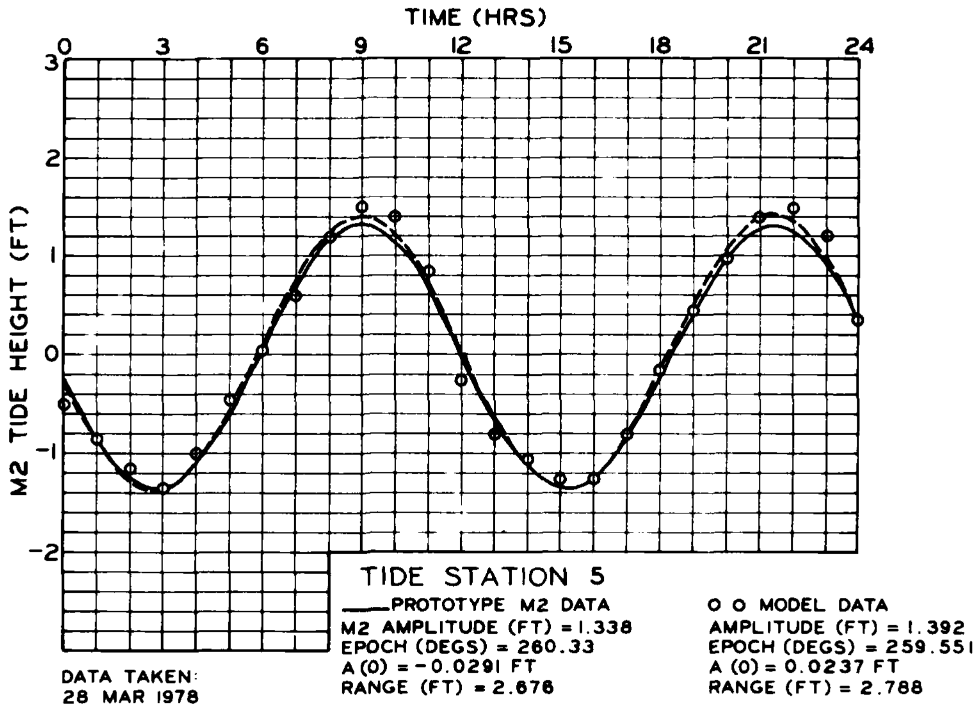




Plate B2. Model/prototype tide height comparison, sta 3 and 4



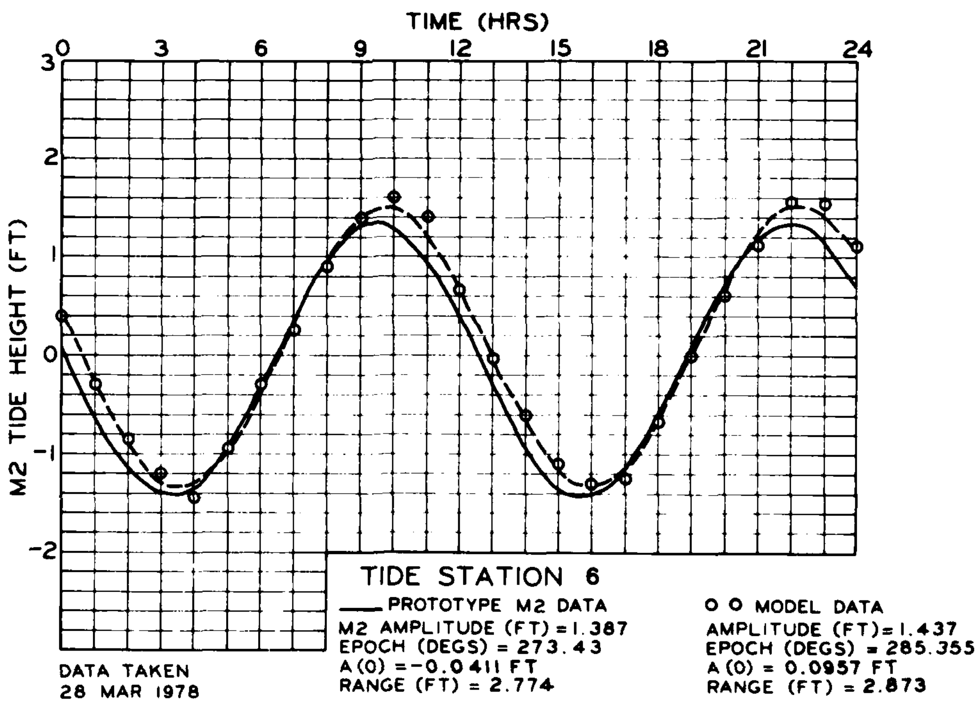
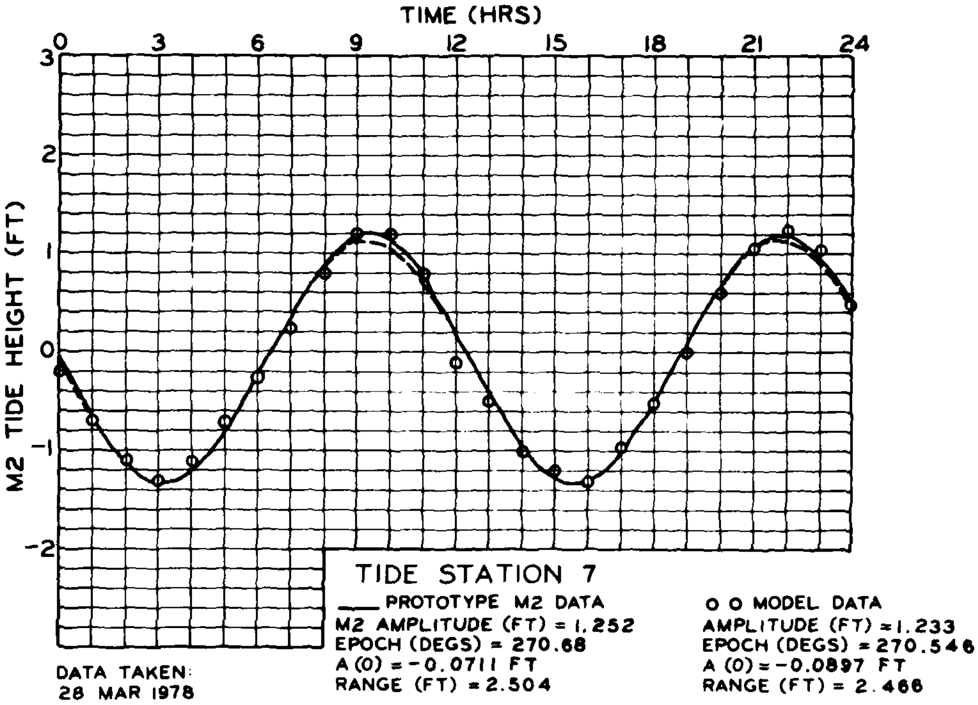




Plate B3. Model/prototype tide height comparison, sta 5 and 6



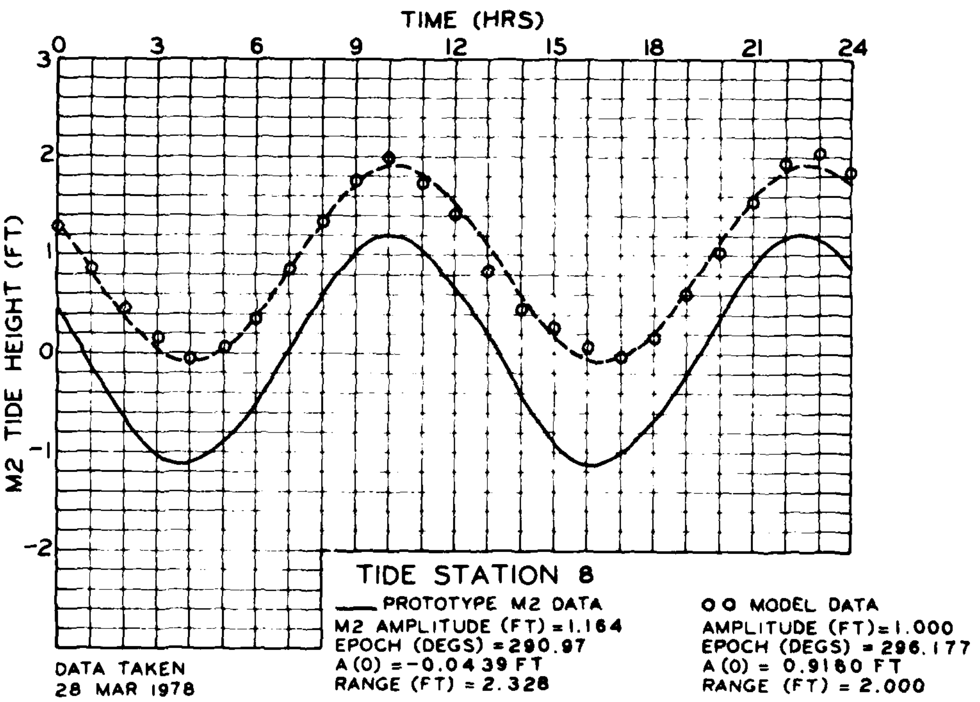
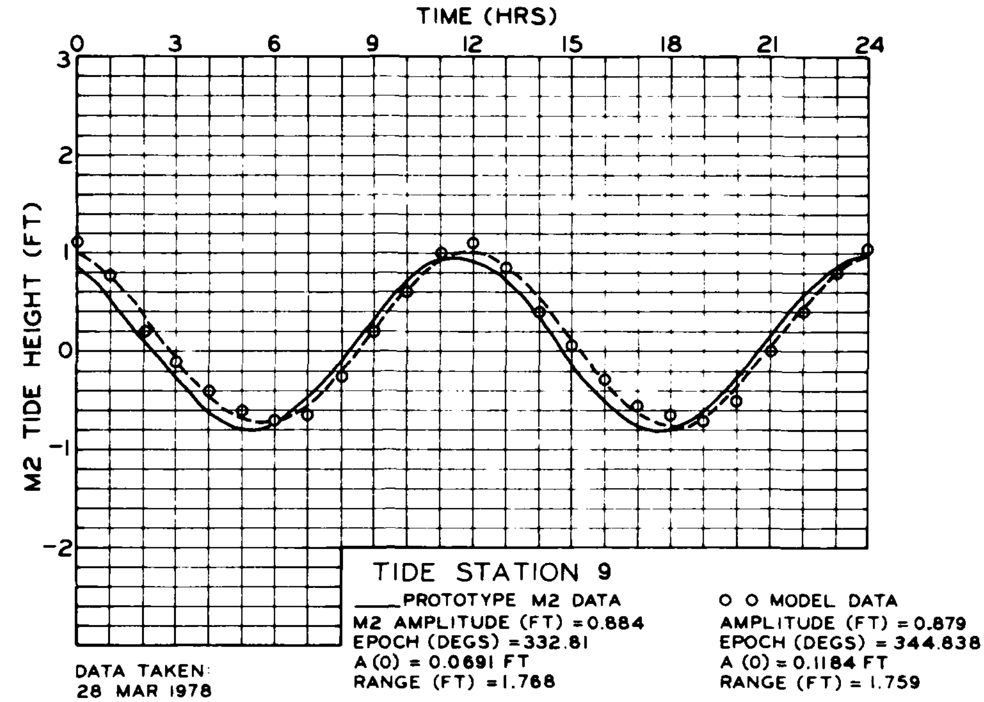




Plate B4. Model/prototype tide height comparison, sta 7 and 8



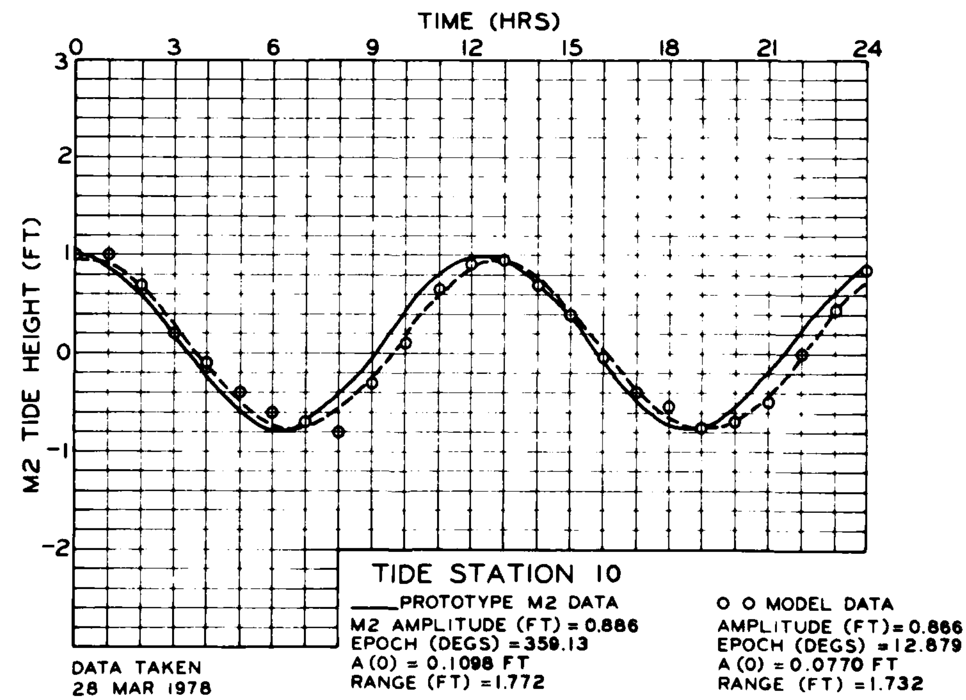
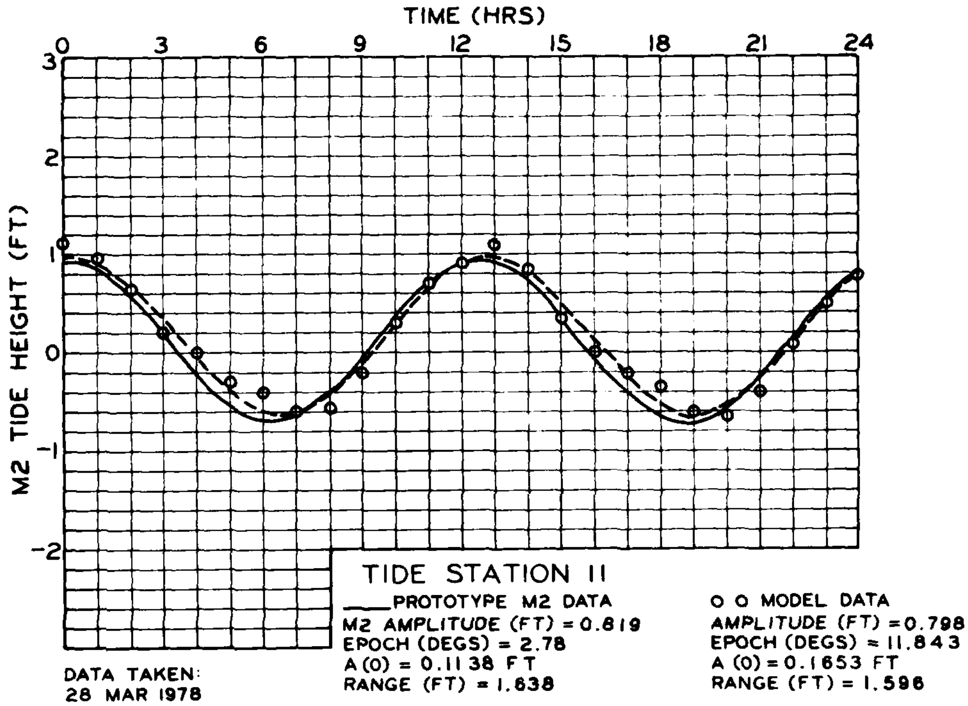




Plate B5. Model/prototype tide height comparison, sta 9 and 10



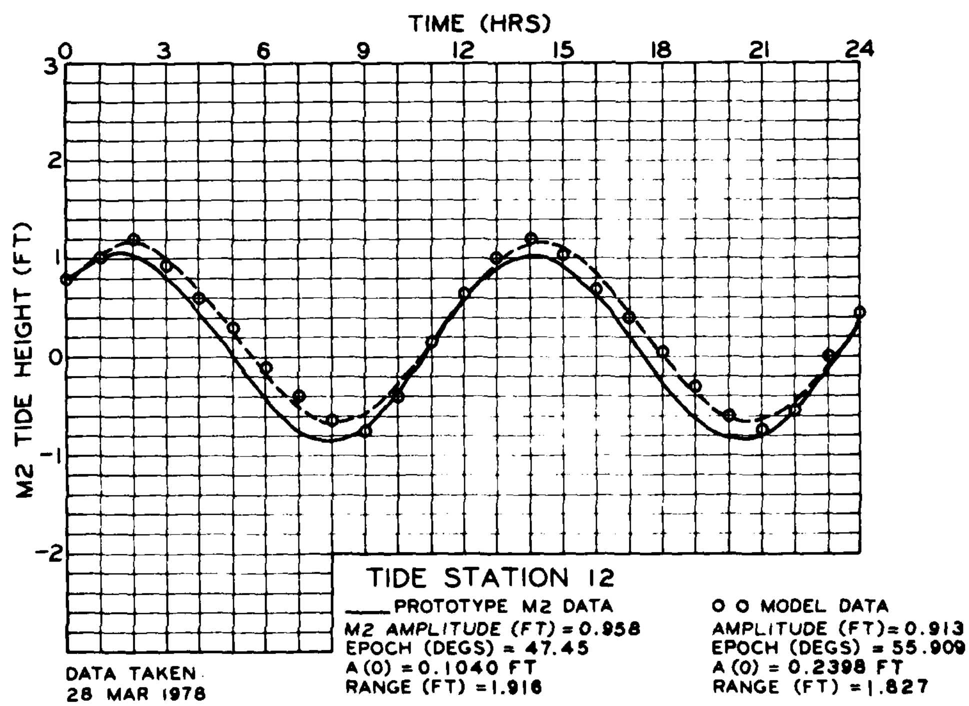
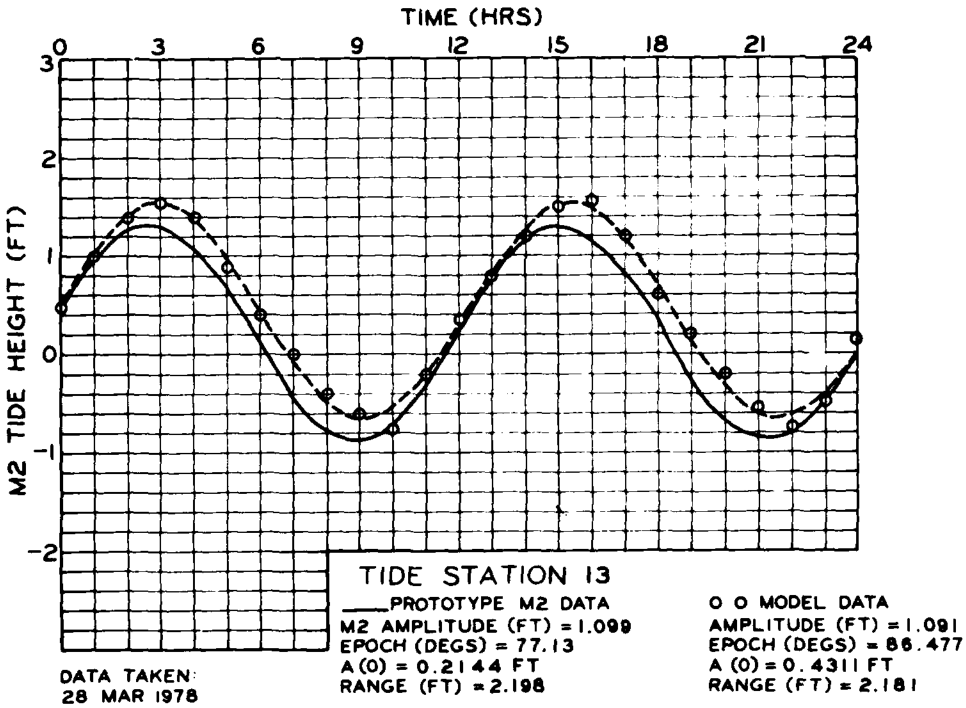




Plate B6. Model/prototype tide height comparison, sta 11 and 12



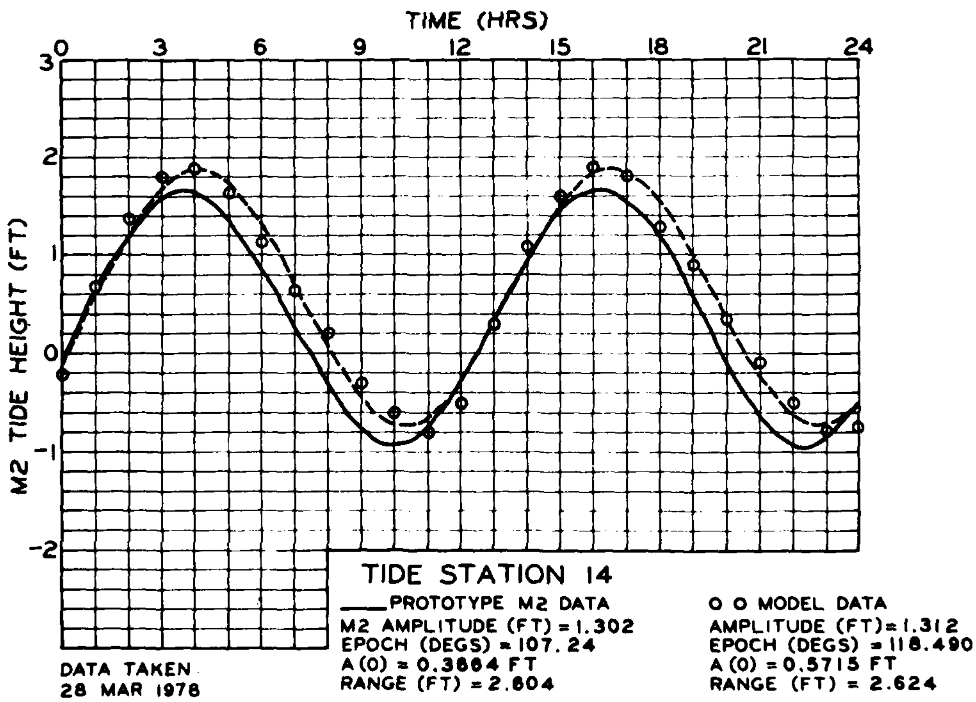
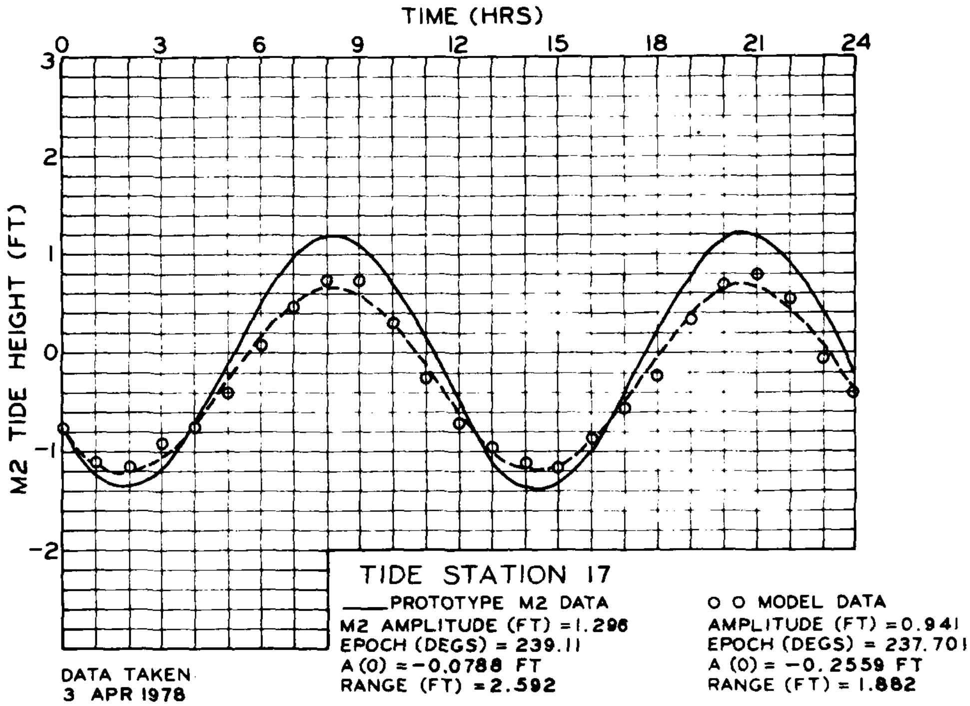




Plate B7. Model/prototype tide height comparison, sta 13 and 14



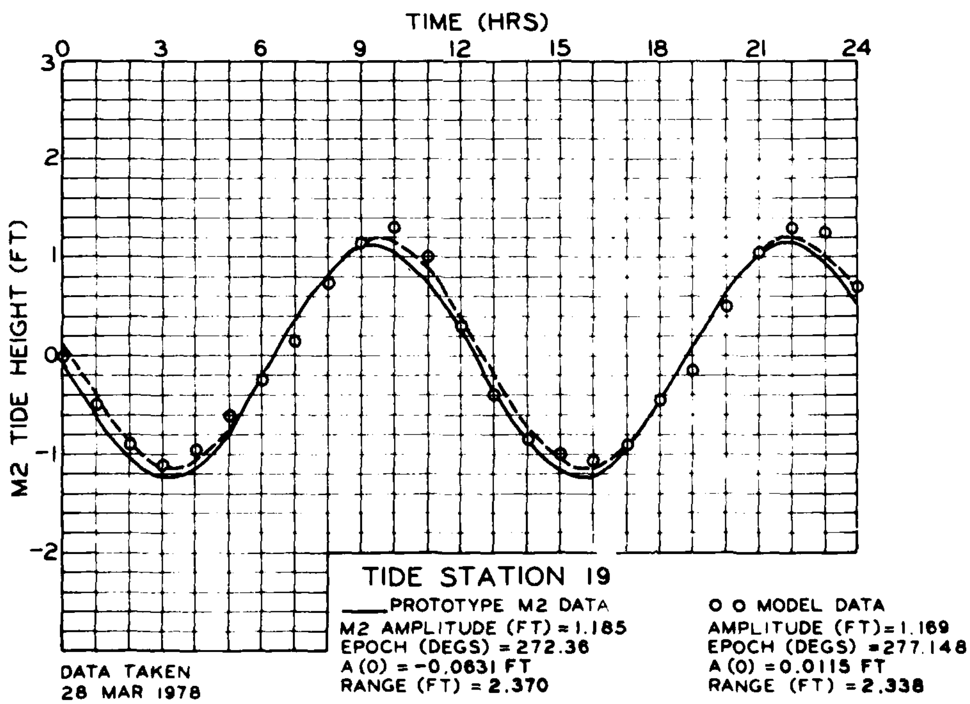
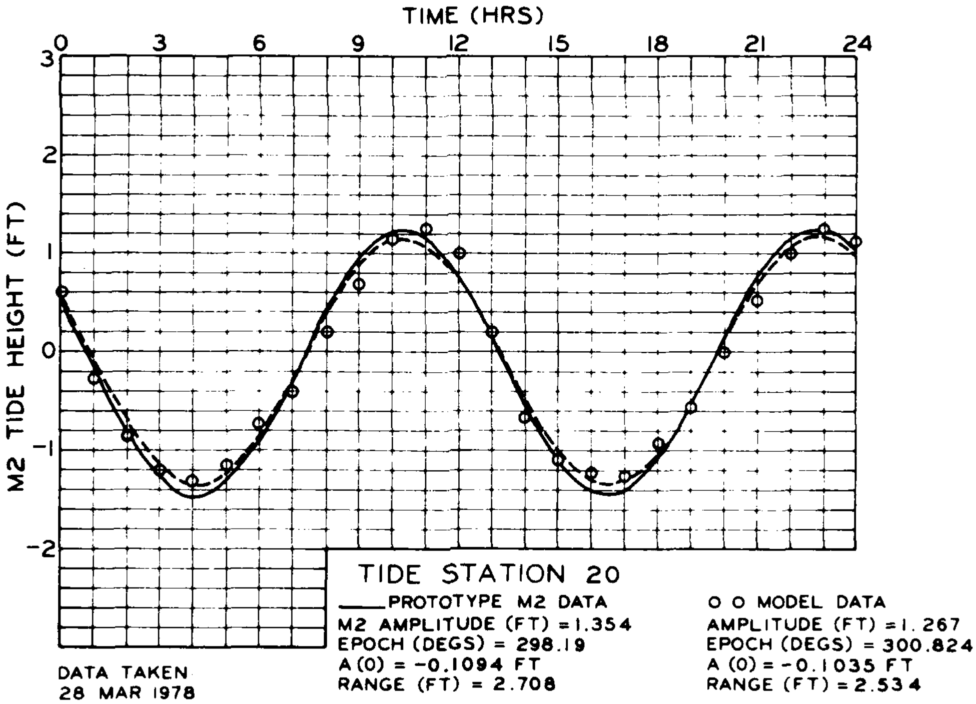




Plate B8. Model/prototype tide height comparison, sta 17 and 19



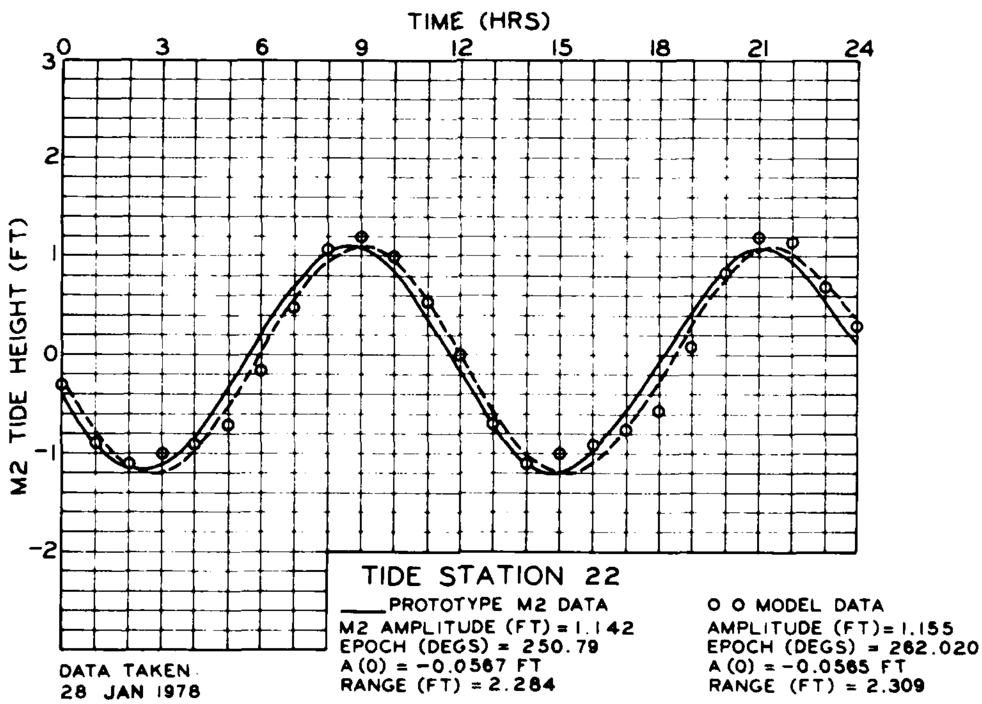
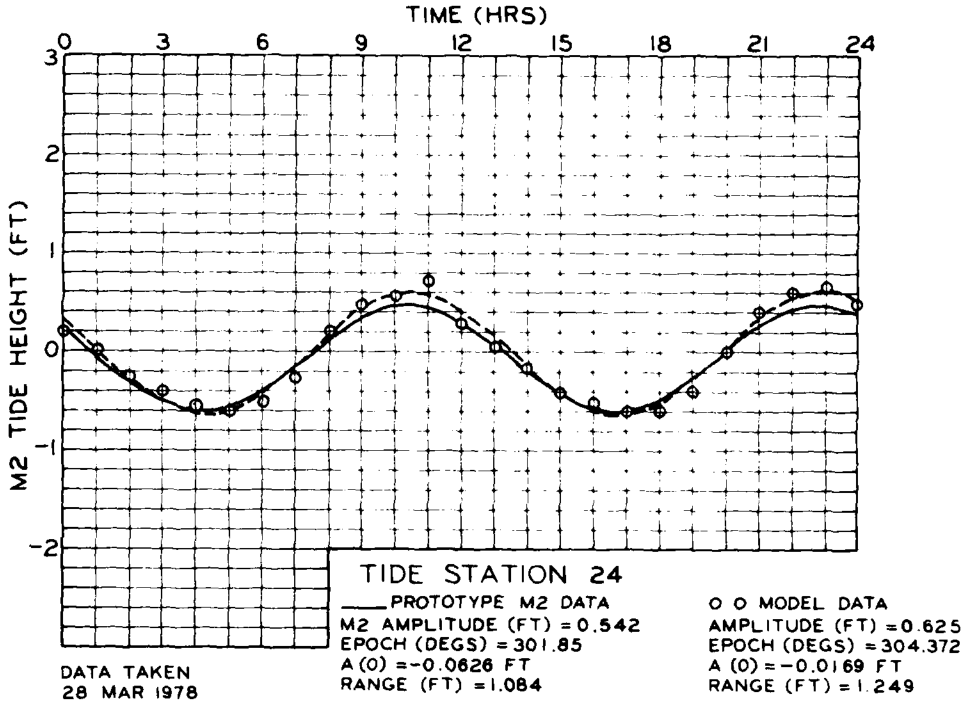




Plate B9. Model/prototype tide height comparison, sta 20 and 22



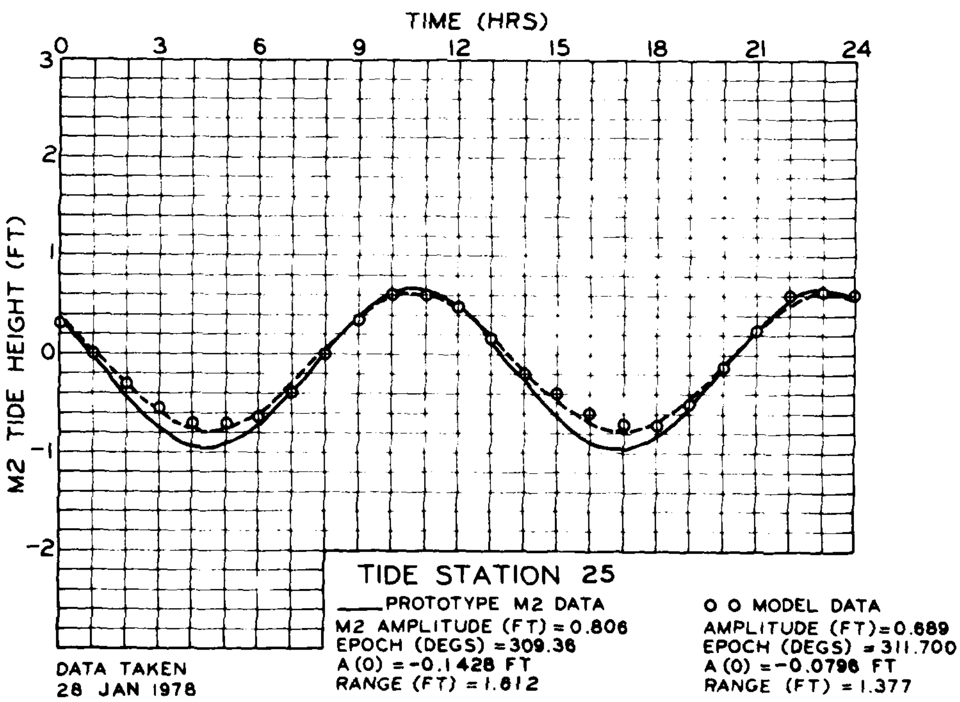
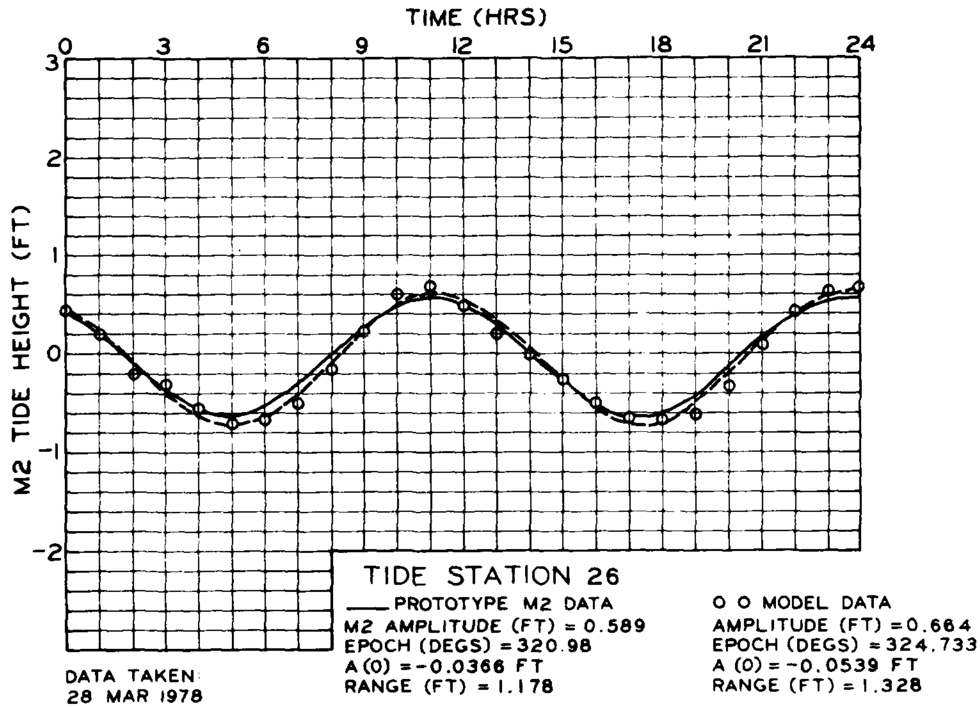




Plate B10. Model/prototype tide height comparison, sta 24 and 25



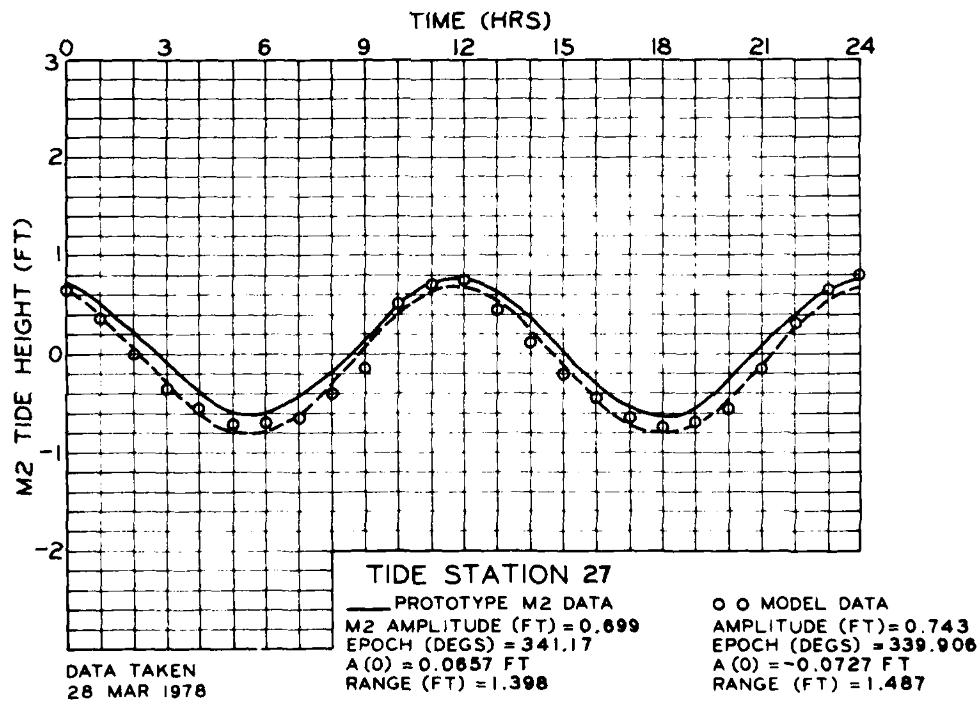
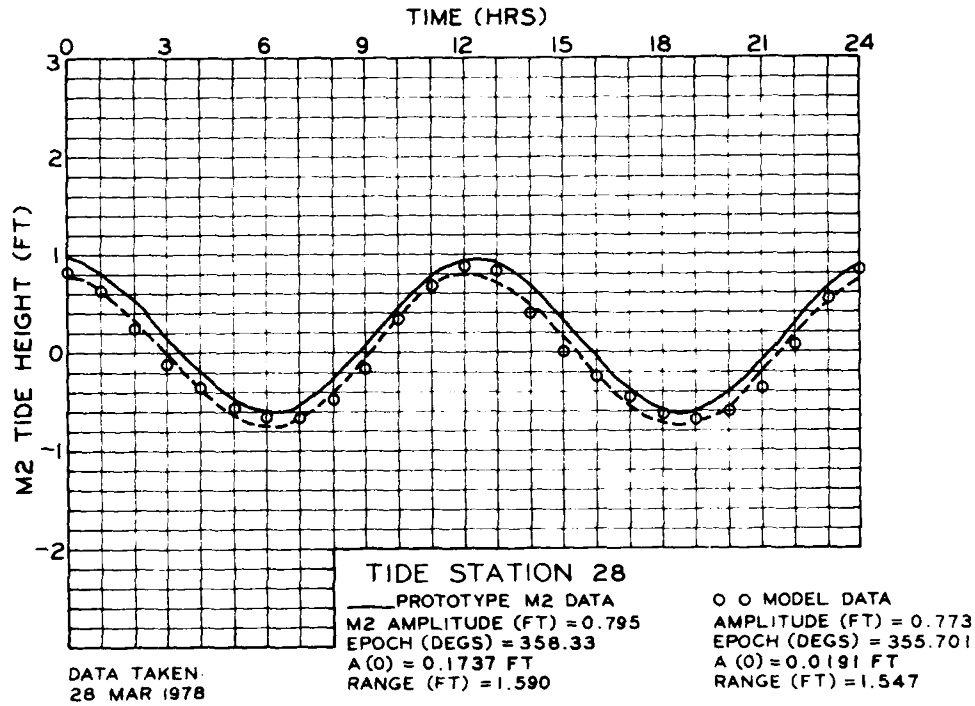




Plate B11. Model/prototype tide height comparison, sta 26 and 27



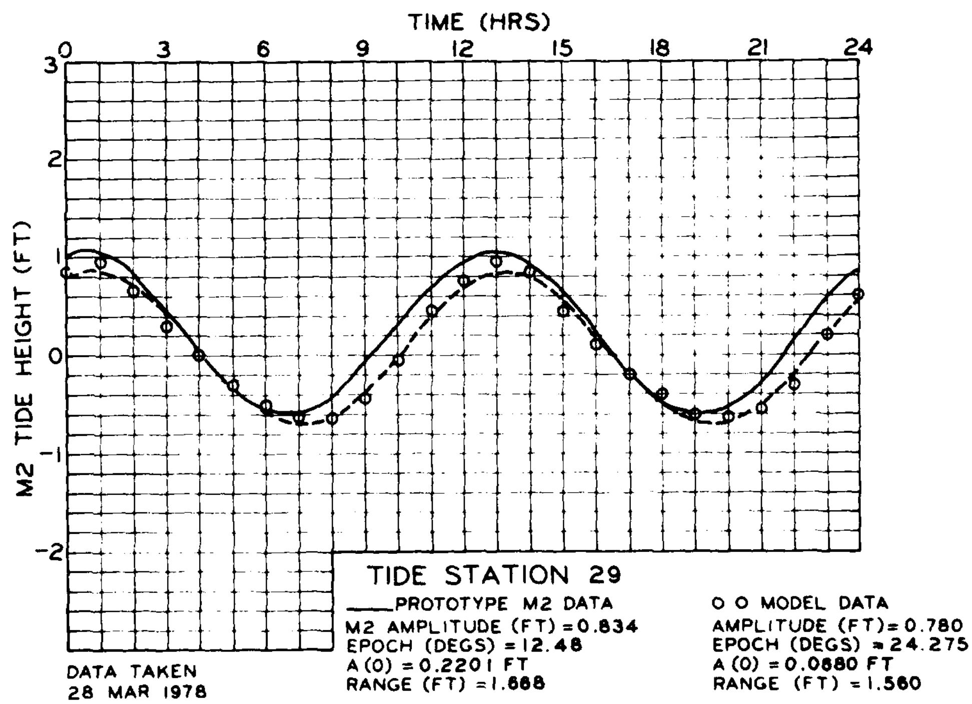
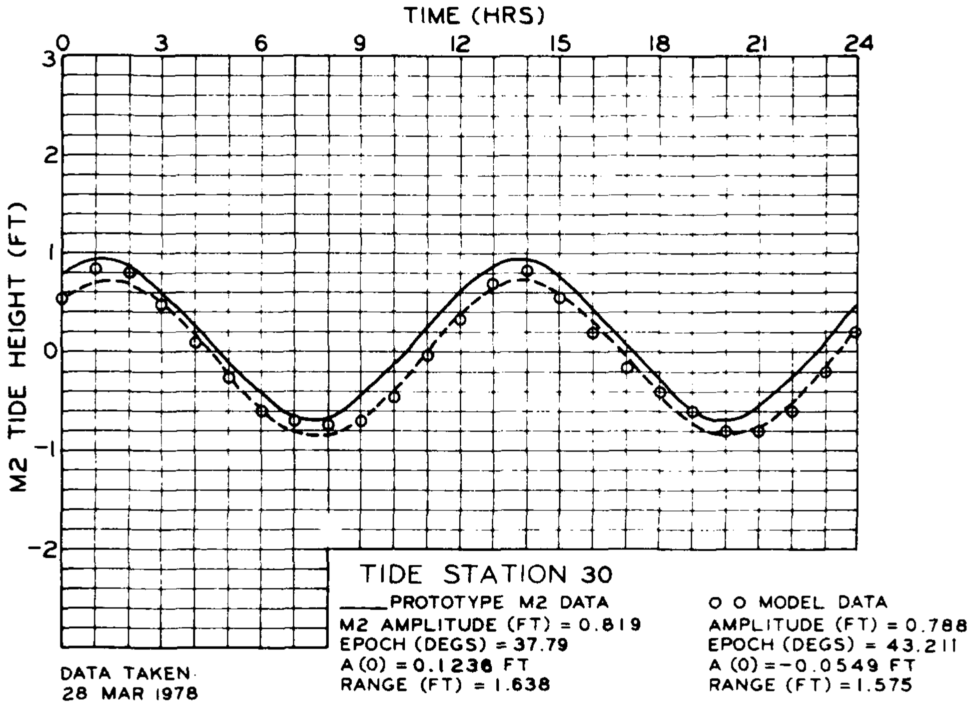




Plate B12. Model/prototype tide height comparison, sta 28 and 29



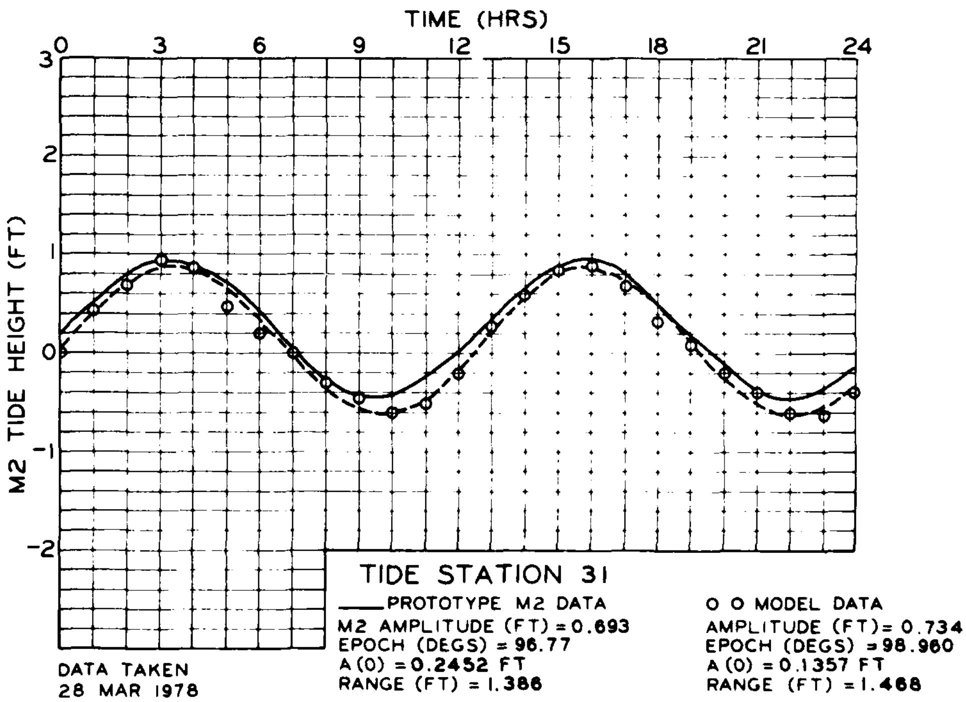
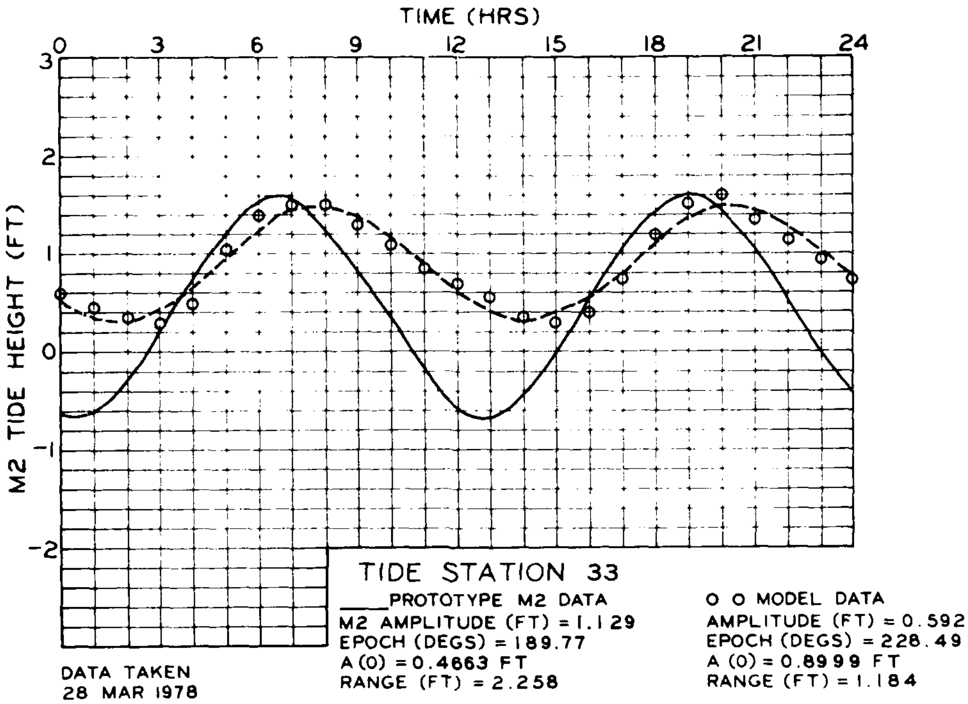




Plate B13. Model/prototype tide height comparison, sta 30 and 31



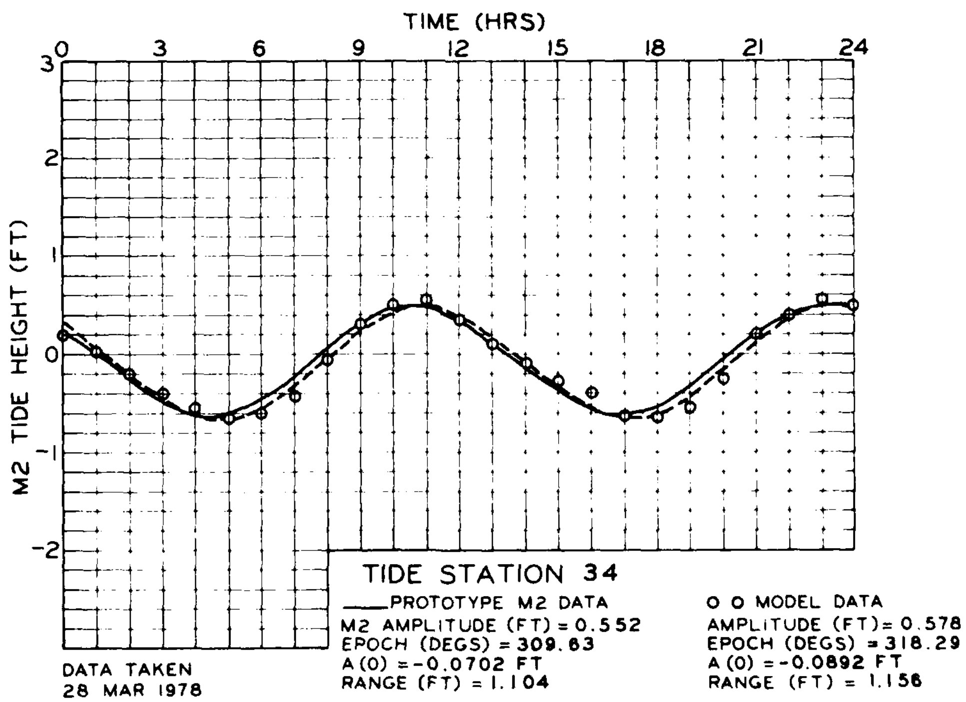
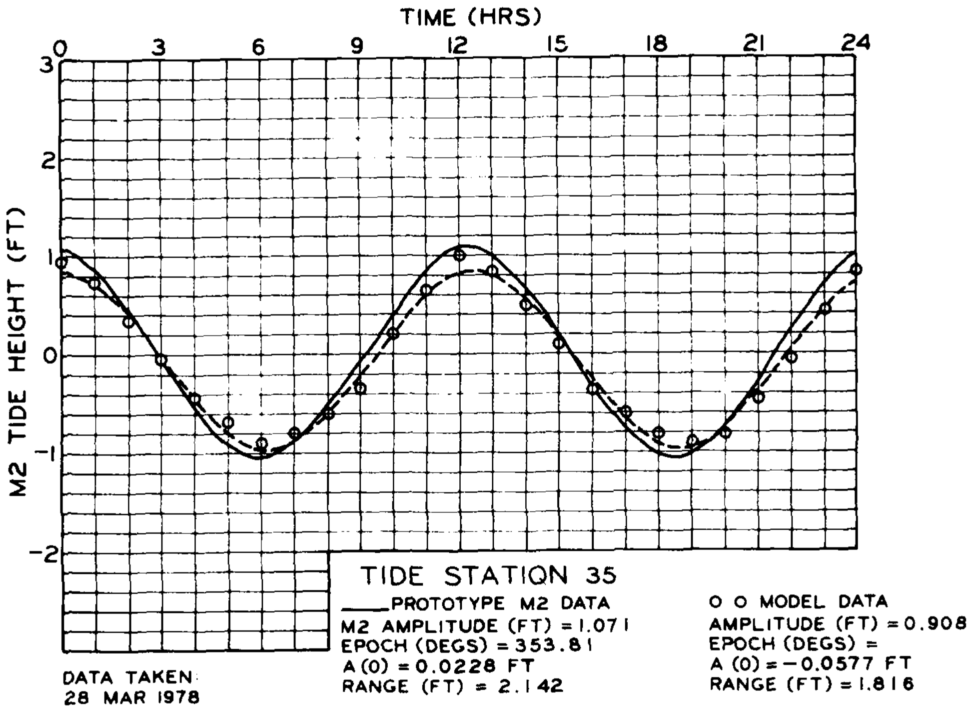




Plate B14. Model/prototype tide height comparison, sta 33 and 34



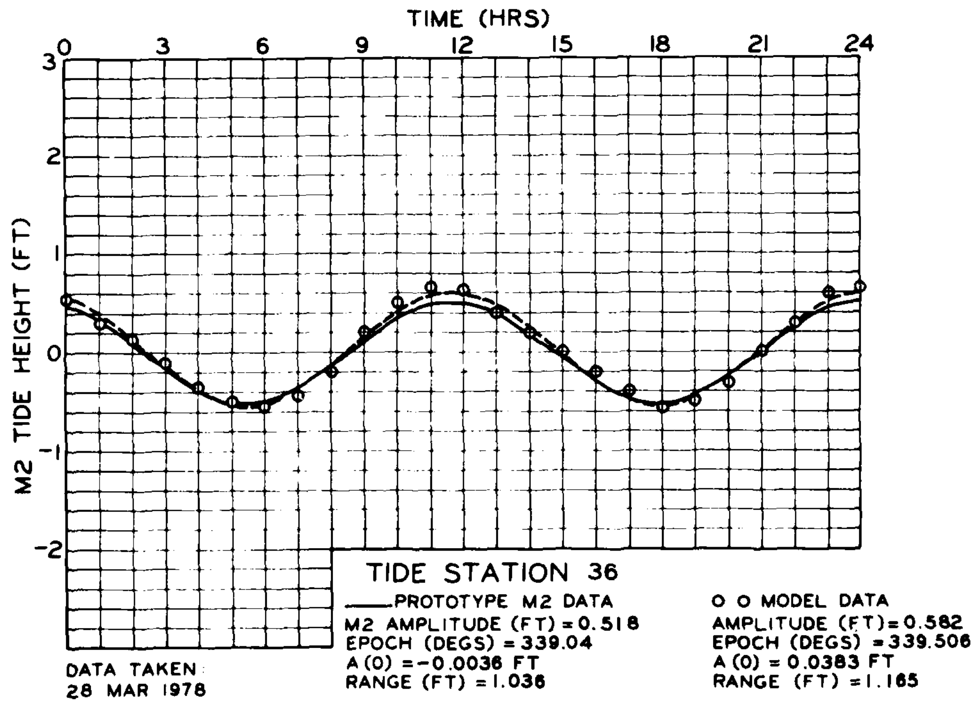
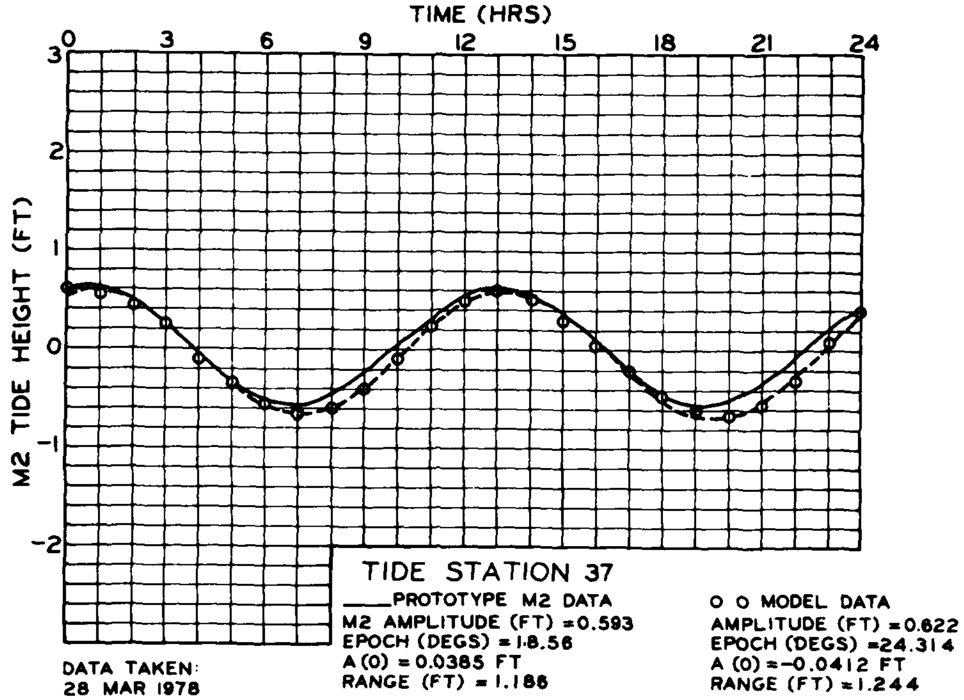




Plate B15. Model/prototype tide height comparison, sta 35 and 36



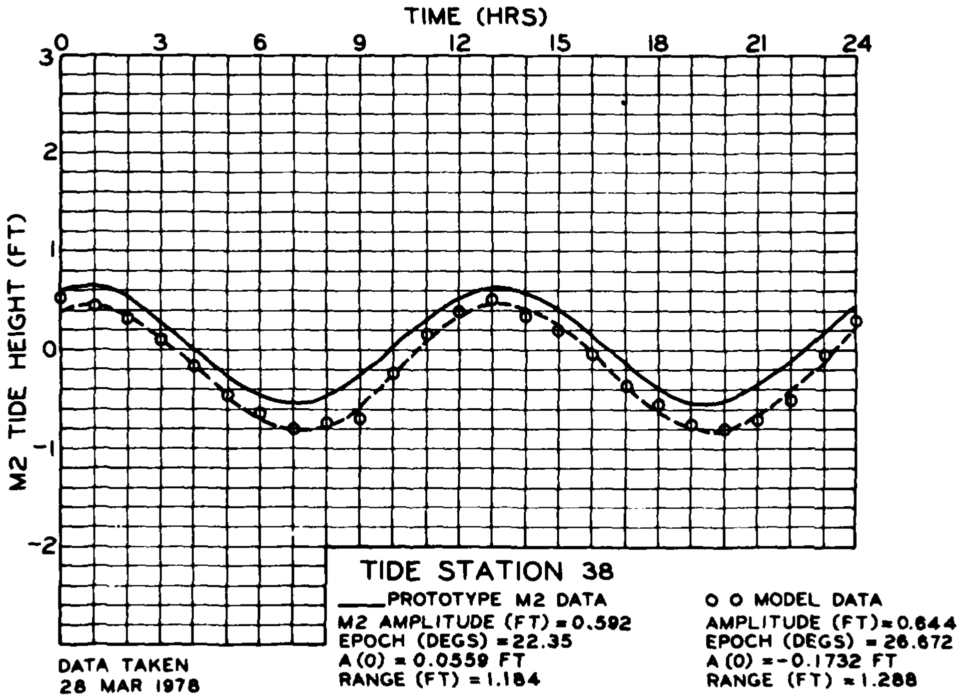
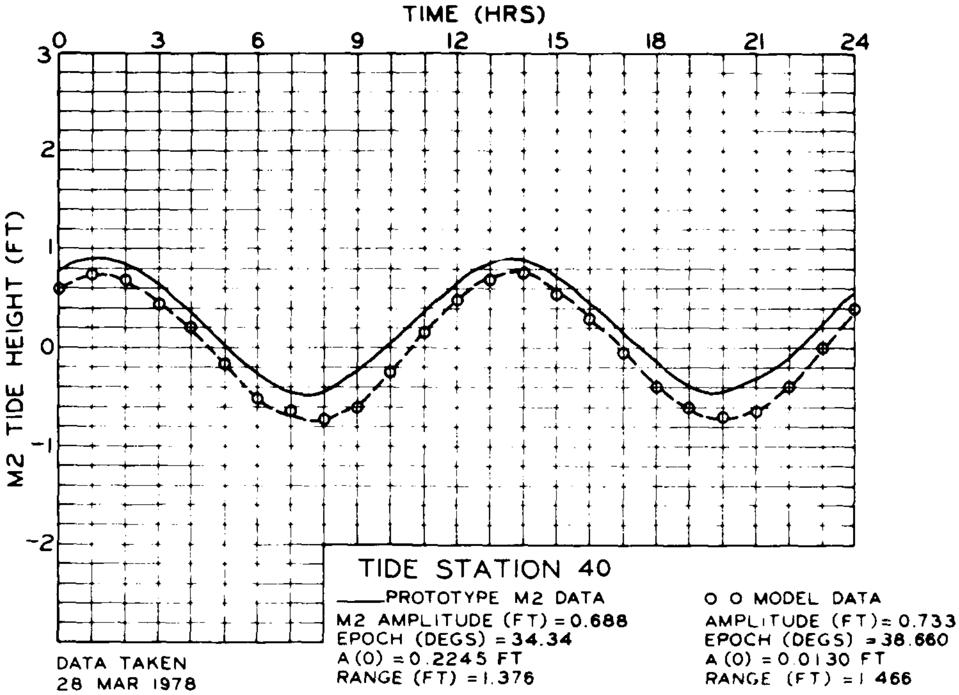




Plate B16. Model/prototype tide height comparison, sta 37 and 38



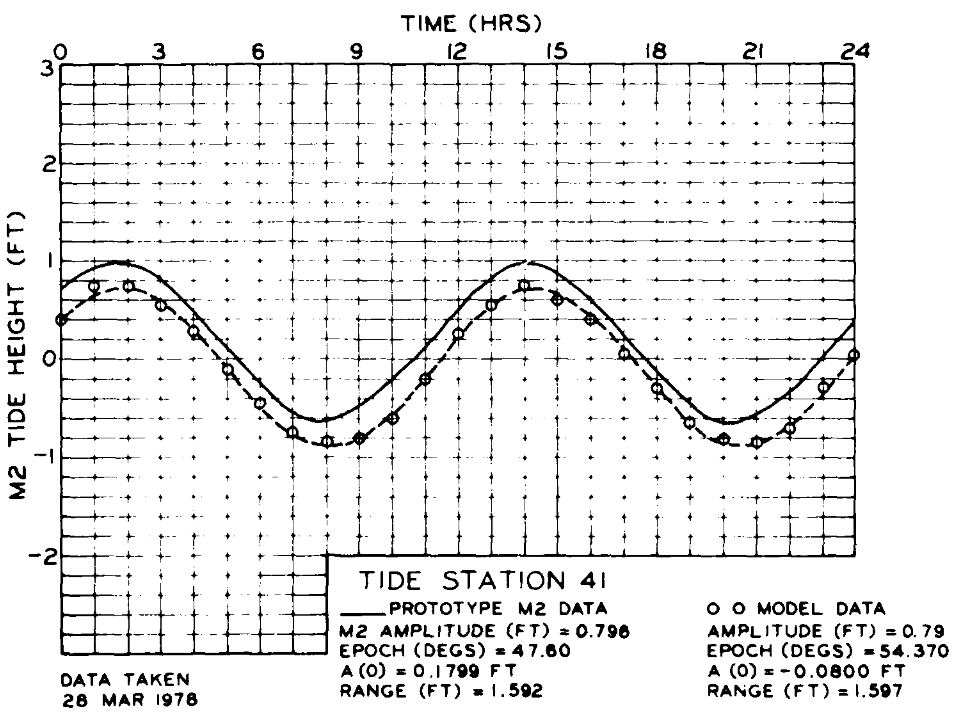
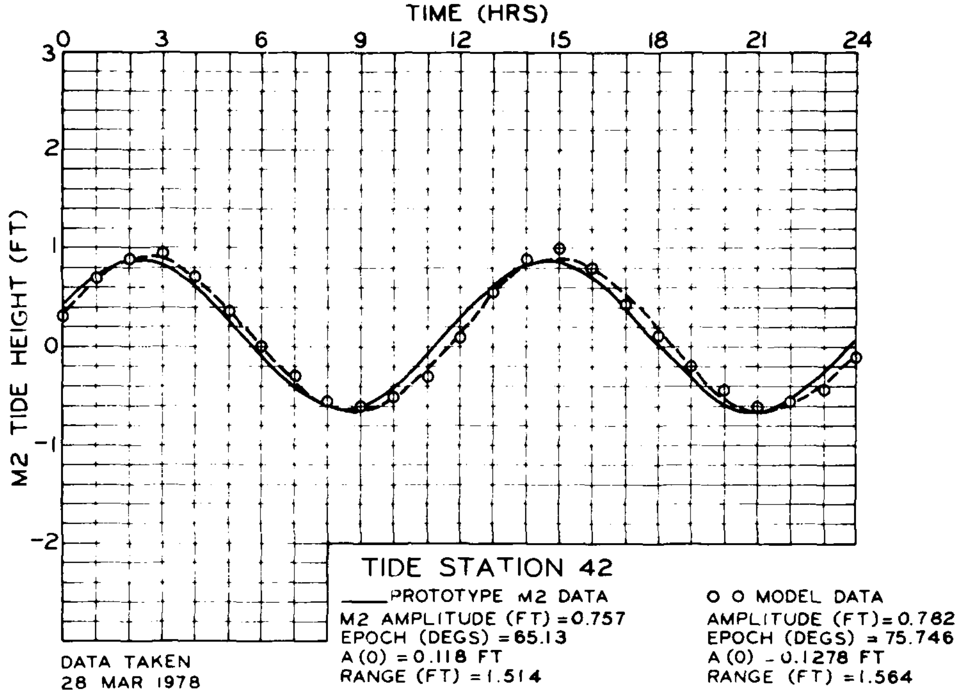




Plate B17. Model/prototype tide height comparison, sta 40 and 41



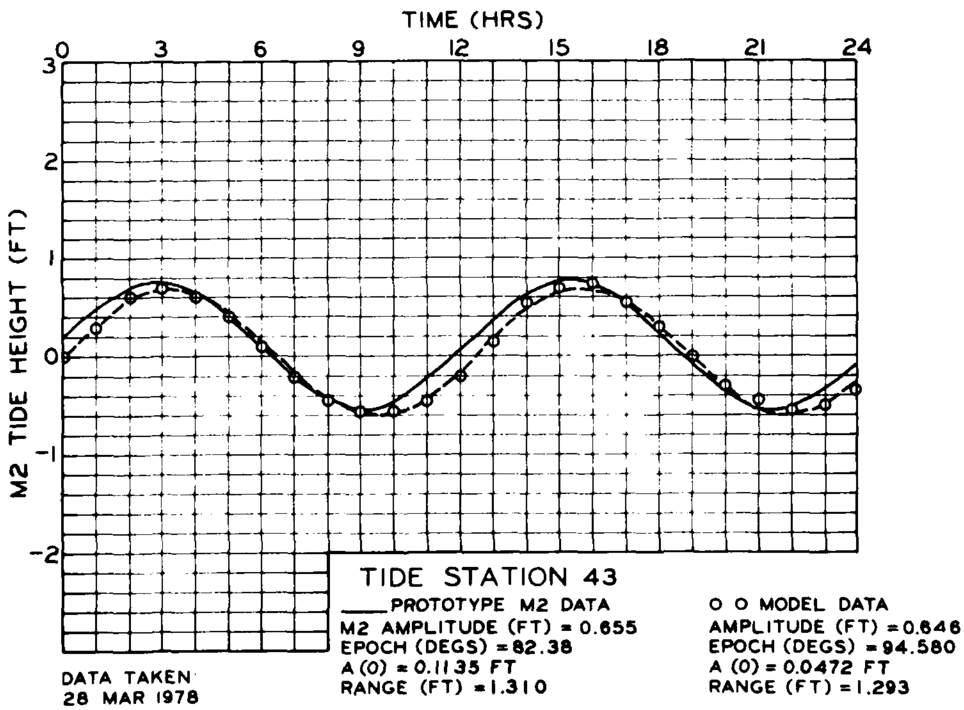
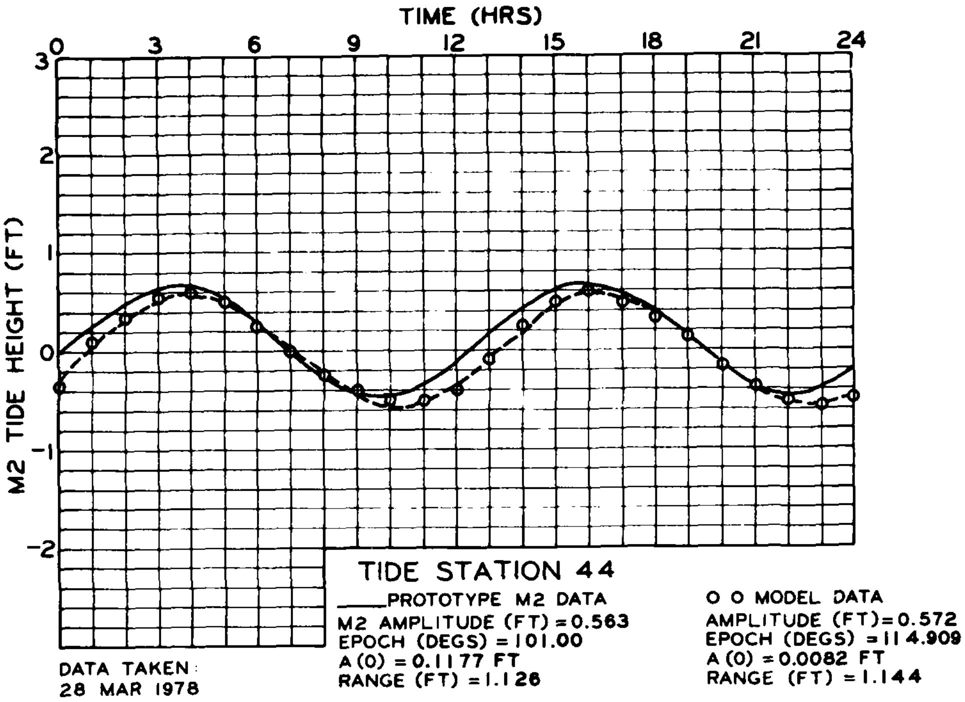




Plate B18. Model/prototype tide height comparison, sta 42 and 43



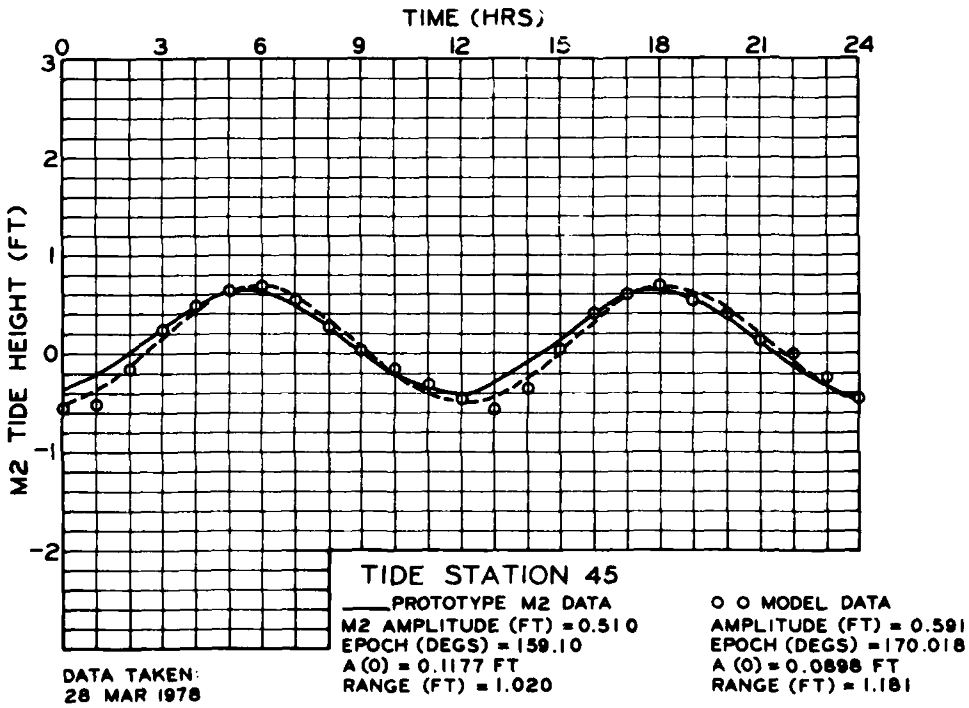
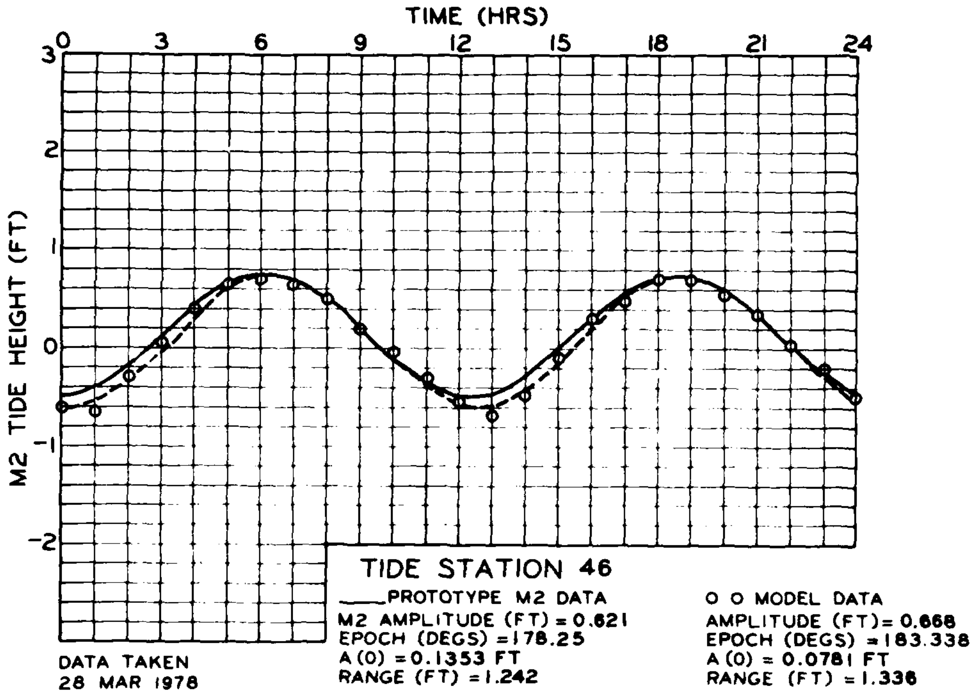




Plate B19. Model/prototype tide height comparison, sta 44 and 45



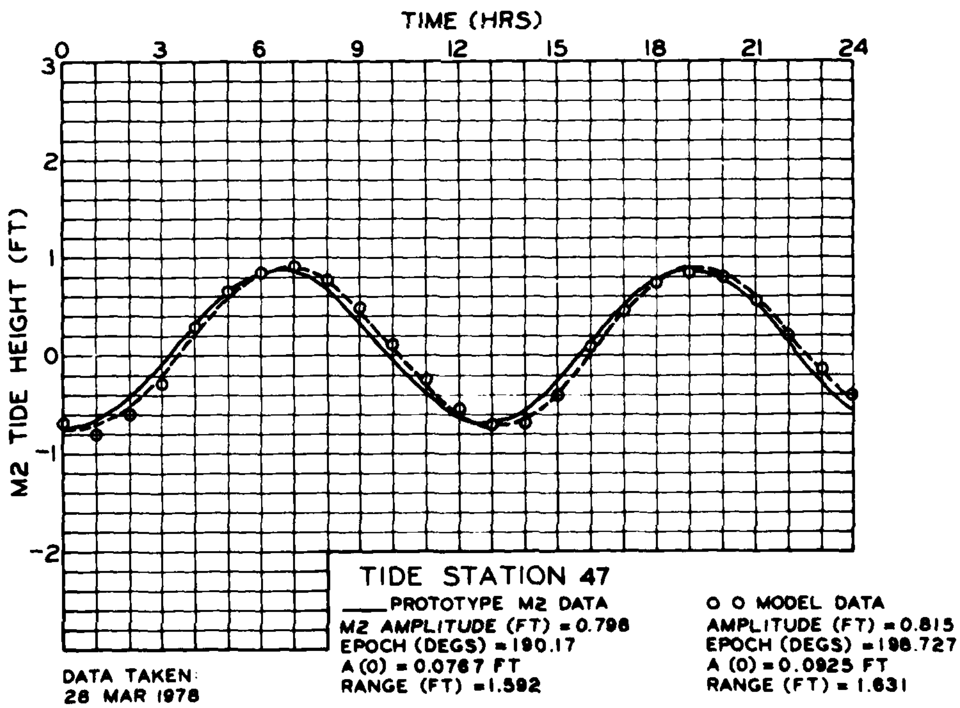




Plate B20. Model/prototype tide height comparison, sta 46 and 47

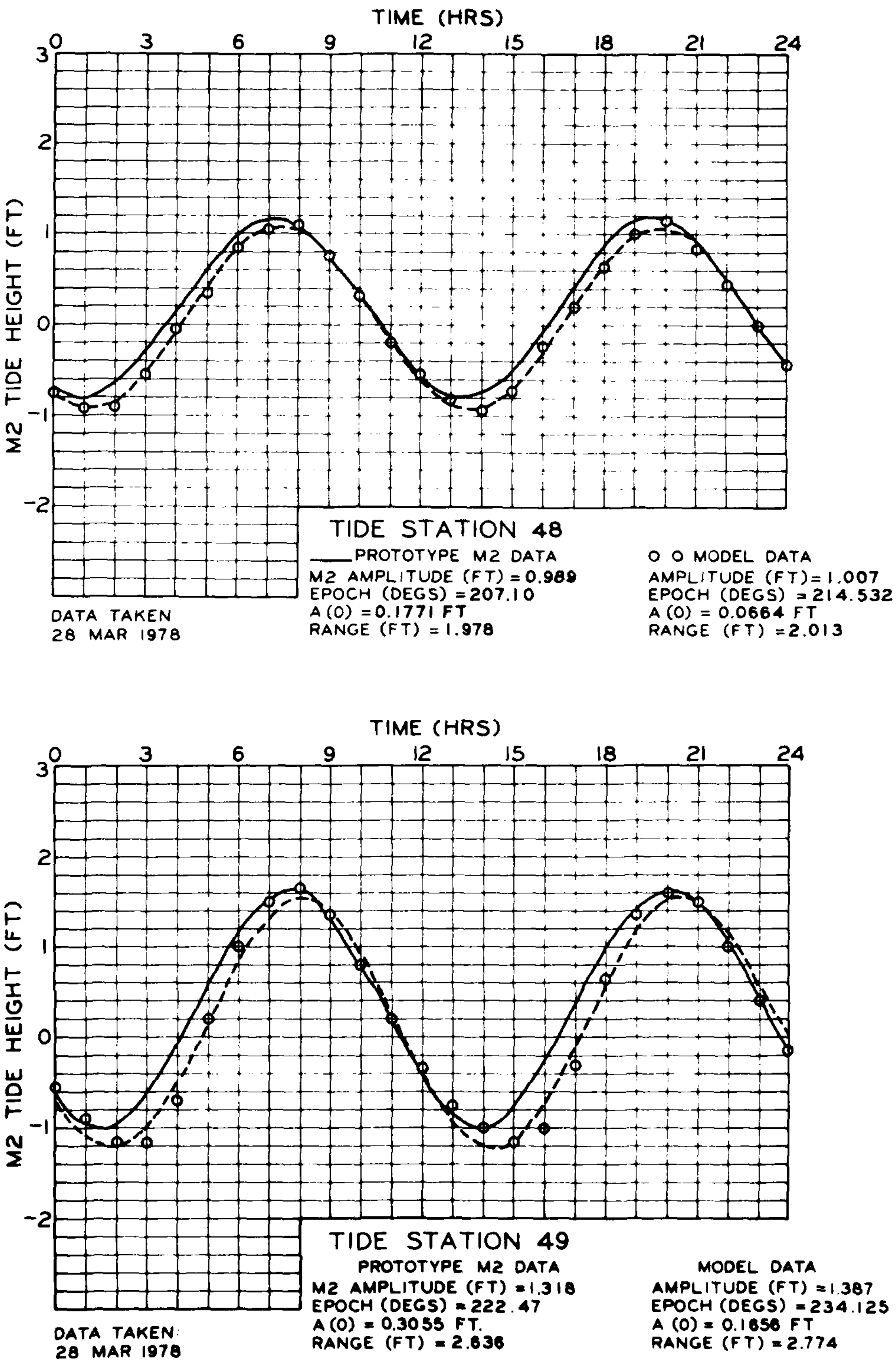
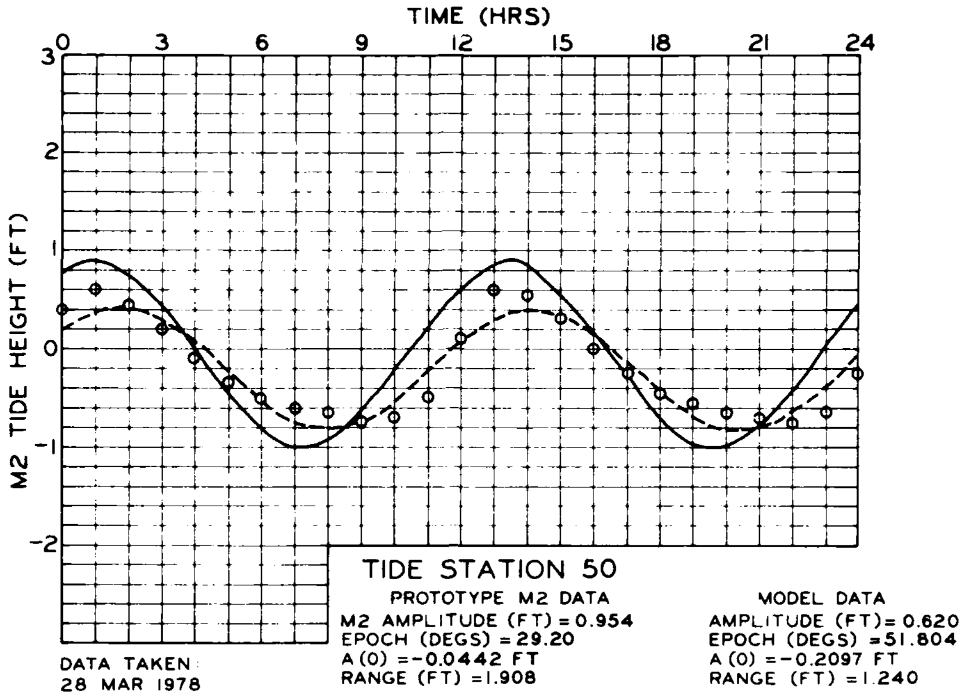



Plate B21. Model/prototype tide height comparison, sta 48 and 49



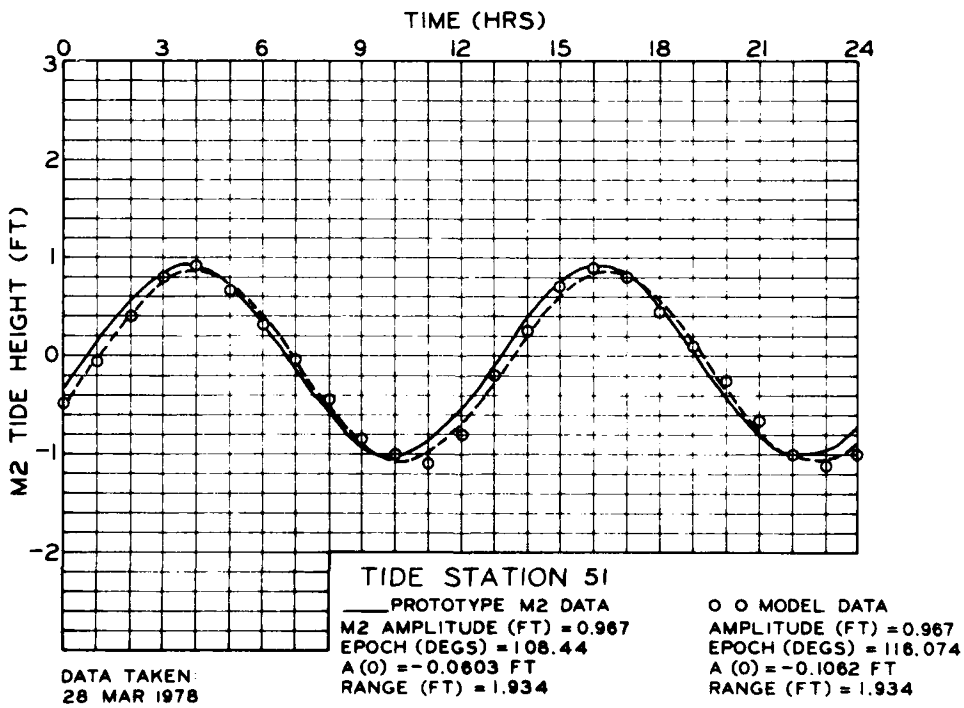
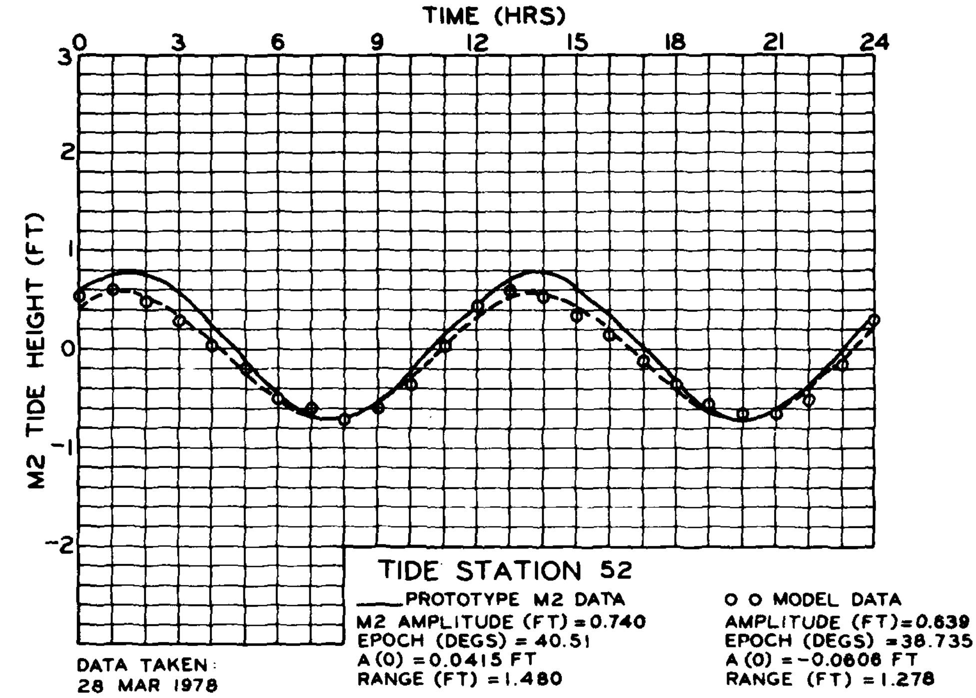




Plate B22. Model/prototype tide height comparison, sta 50 and 51



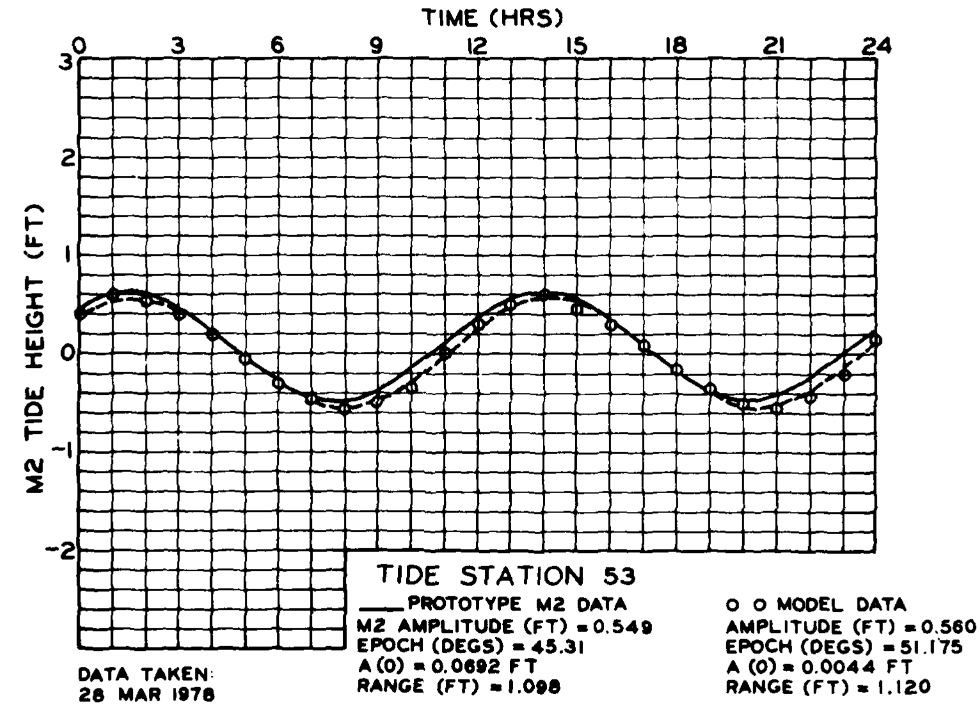
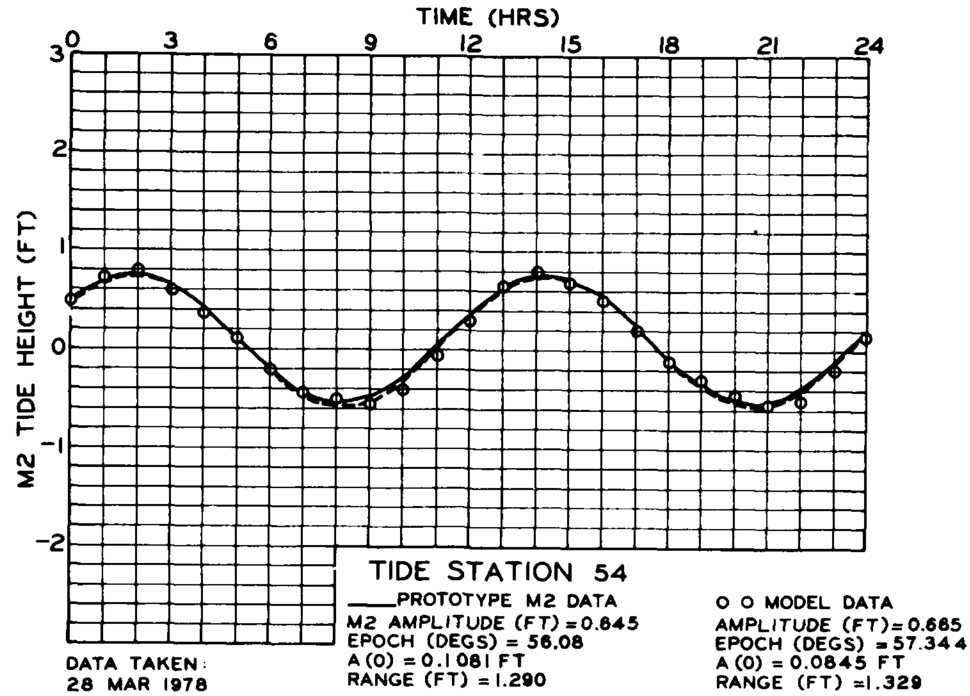




Plate B23. Model/prototype tide height comparison, sta 52 and 53



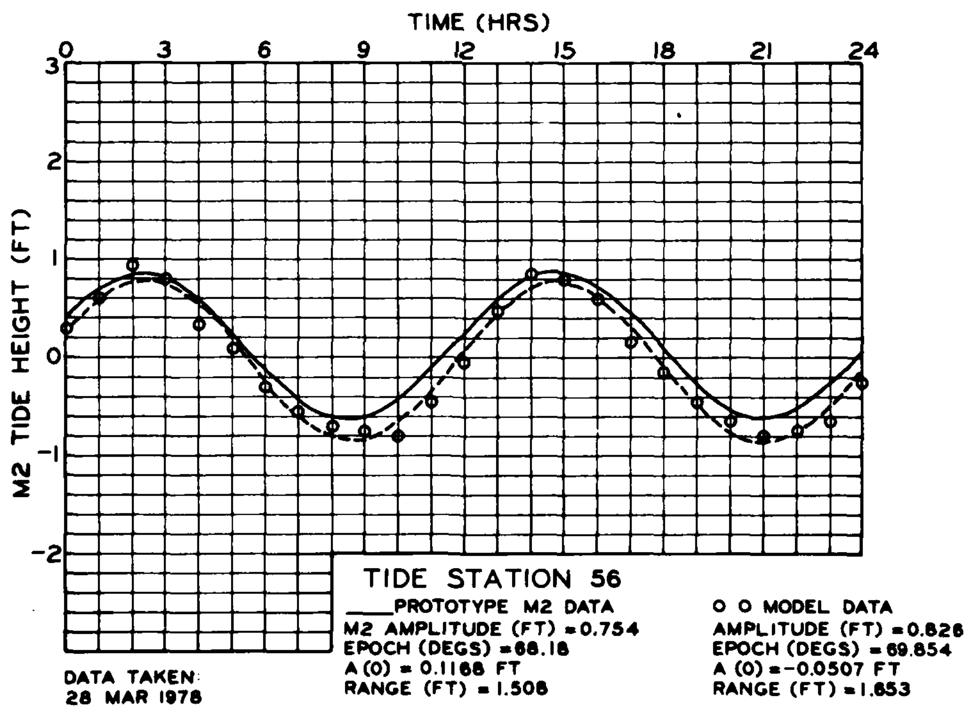
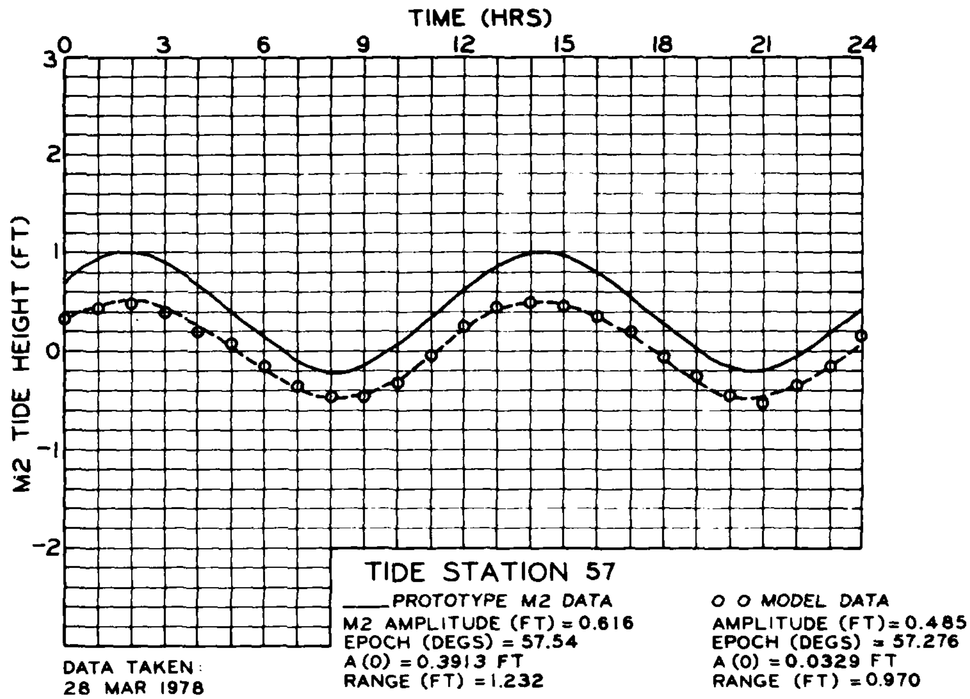




Plate B24. Model/prototype tide height comparison, sta 54 and 56



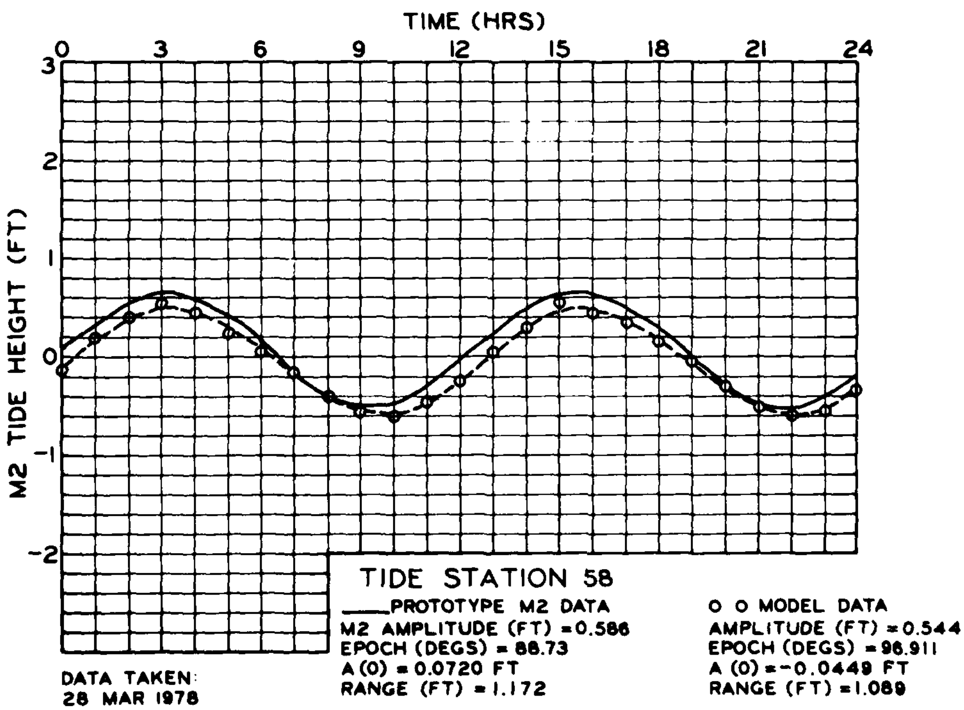
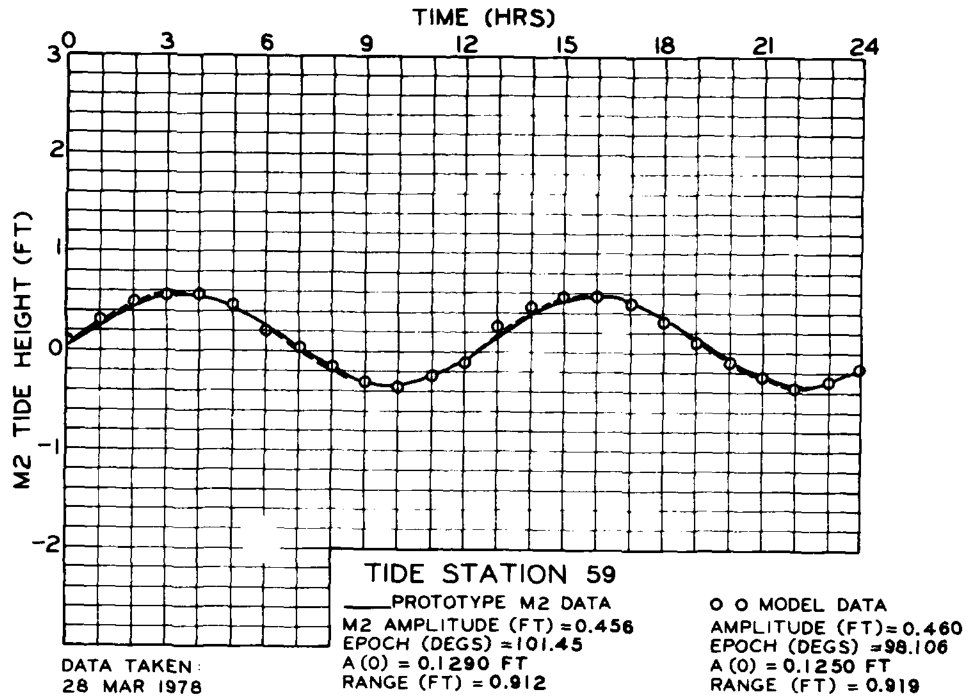




Plate B25. Model/prototype tide height comparison, sta 57 and 58



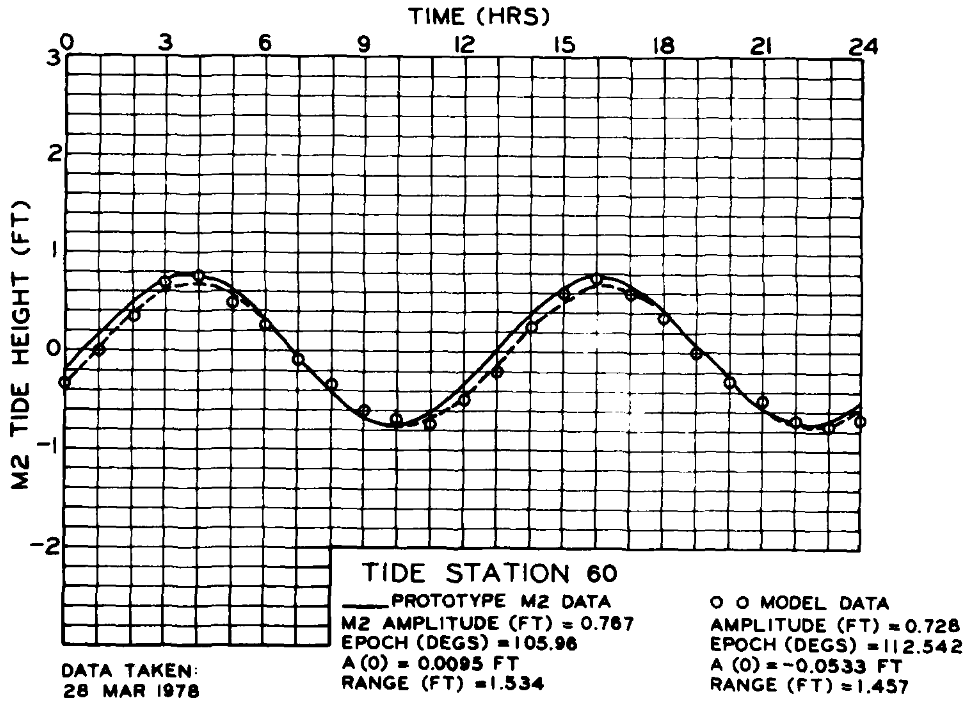
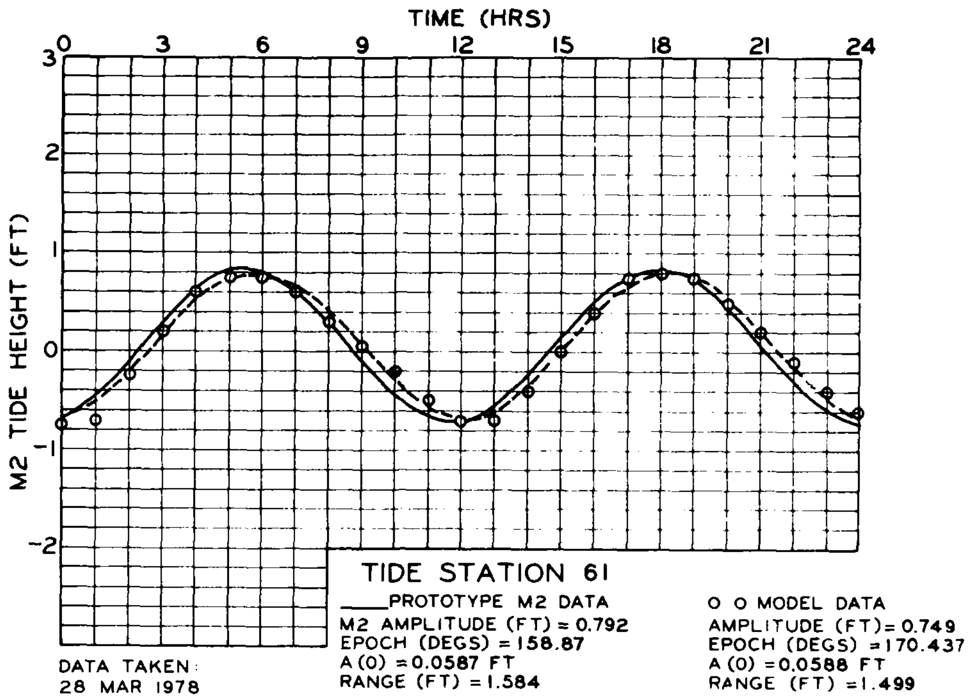




Plate B26. Model/prototype tide height comparison, sta 59 and 60



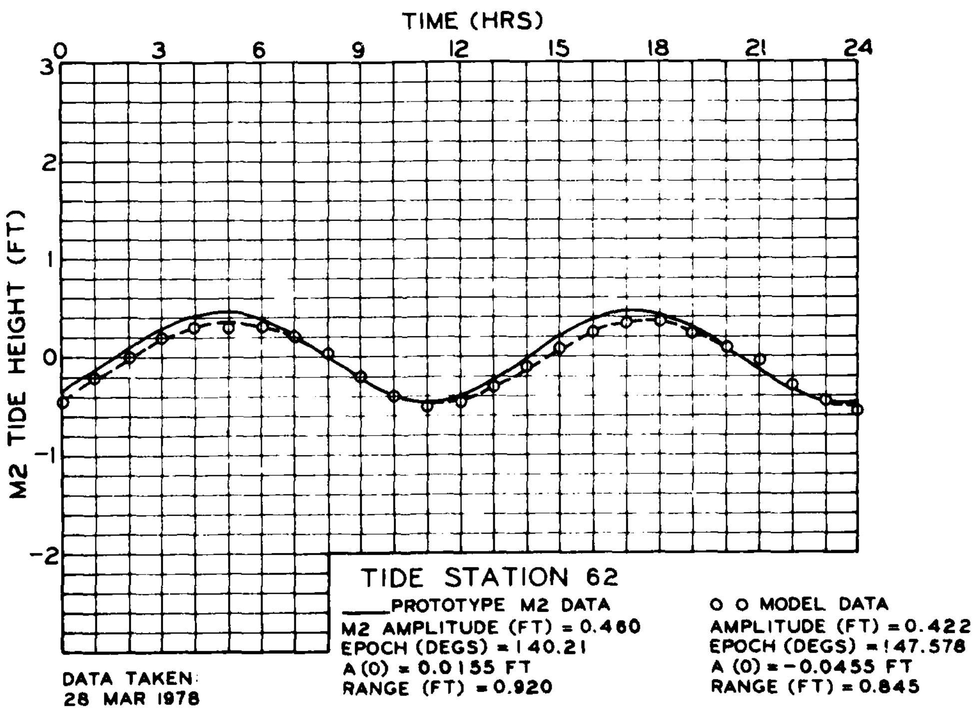
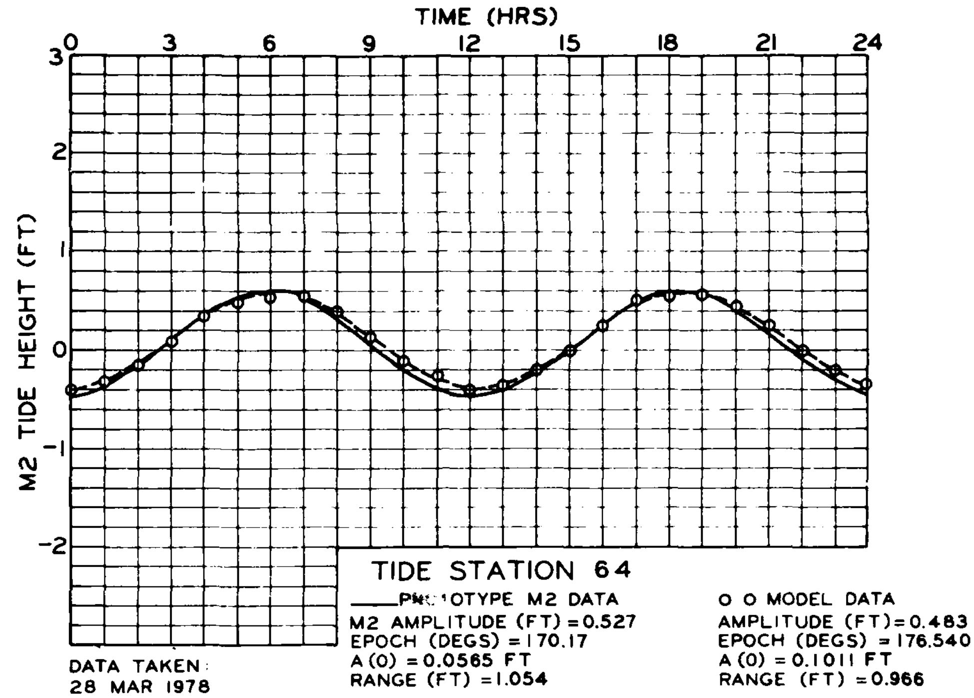




Plate B27. Model/prototype tide height comparison, sta 61 and 62



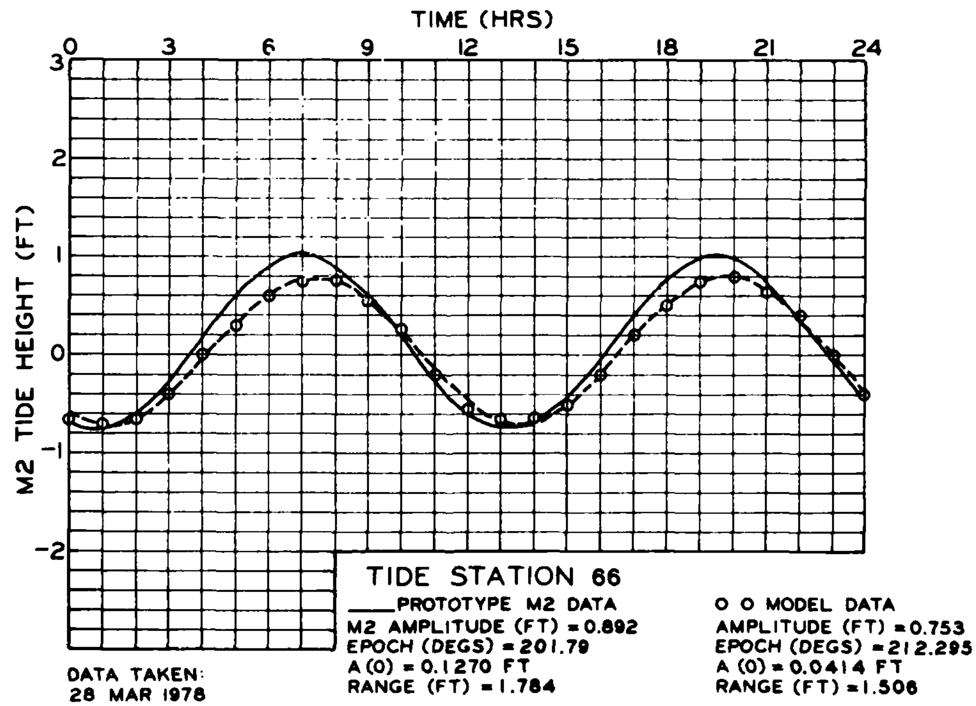
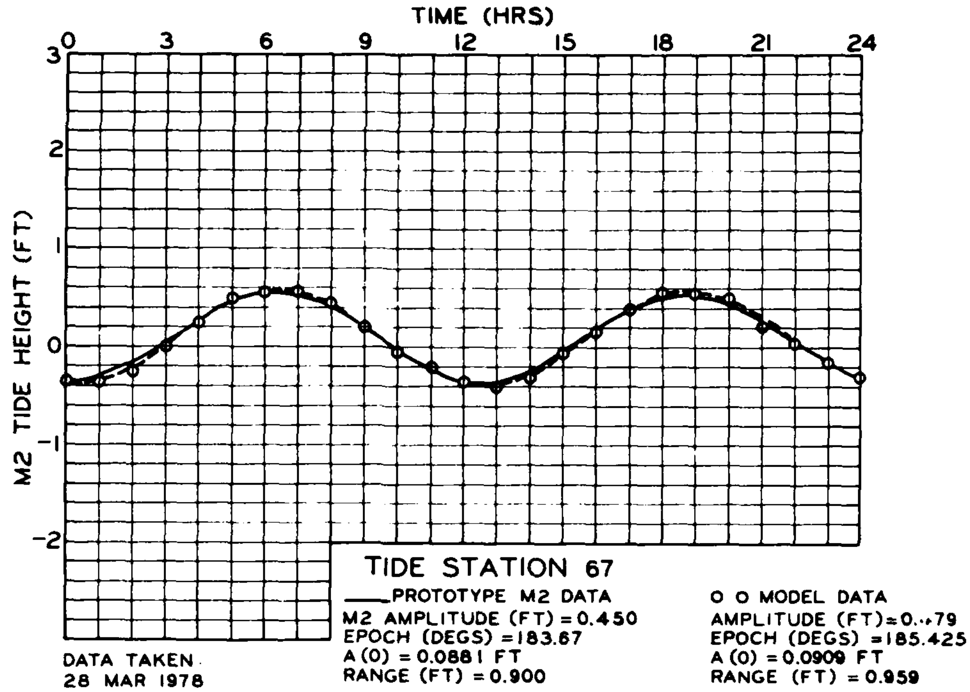




Plate B28. Model/prototype tide height comparison, sta 64 and 66



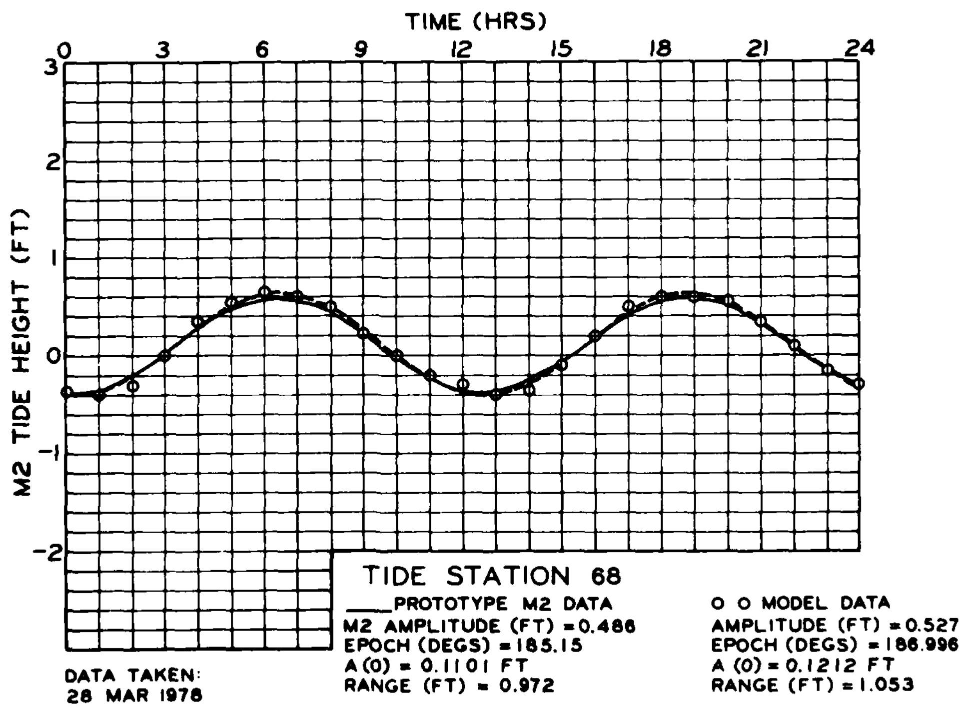
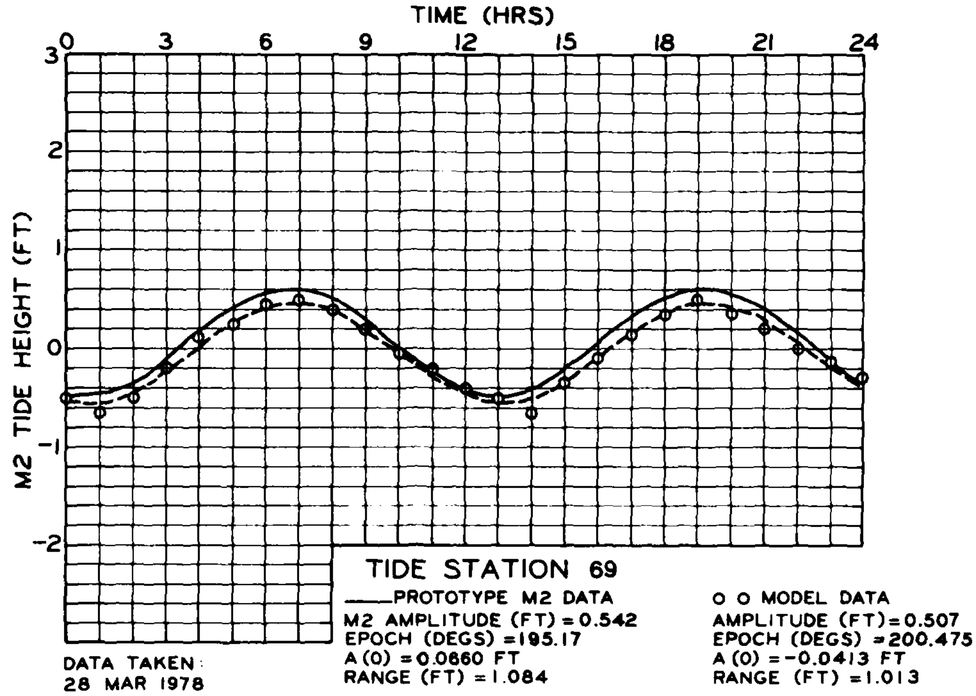




Plate B29. Model/prototype tide height comparison, sta 67 and 68



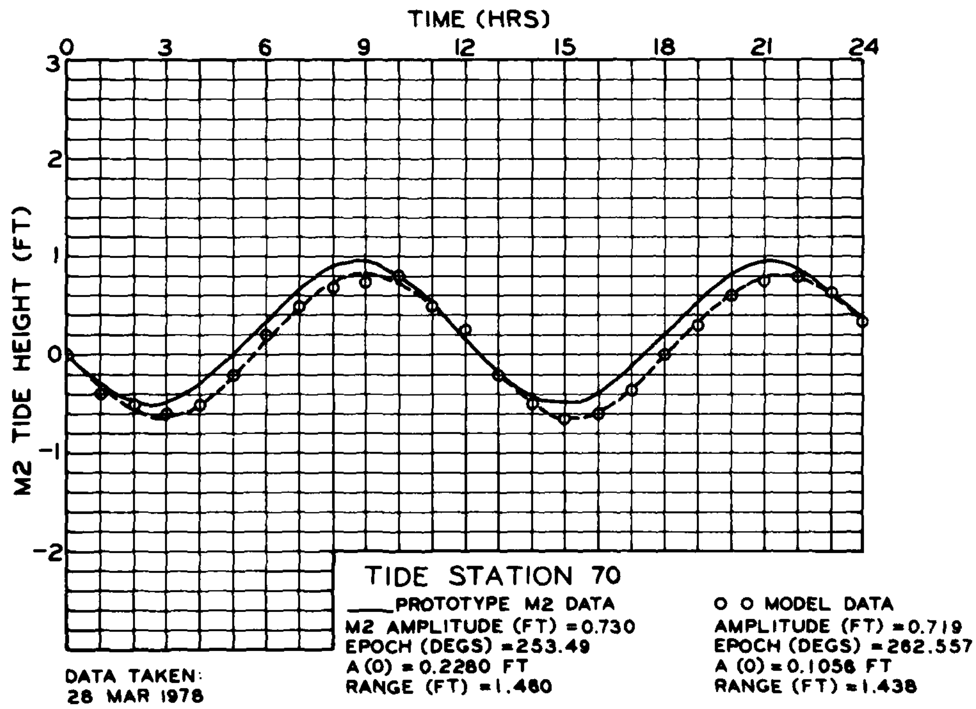
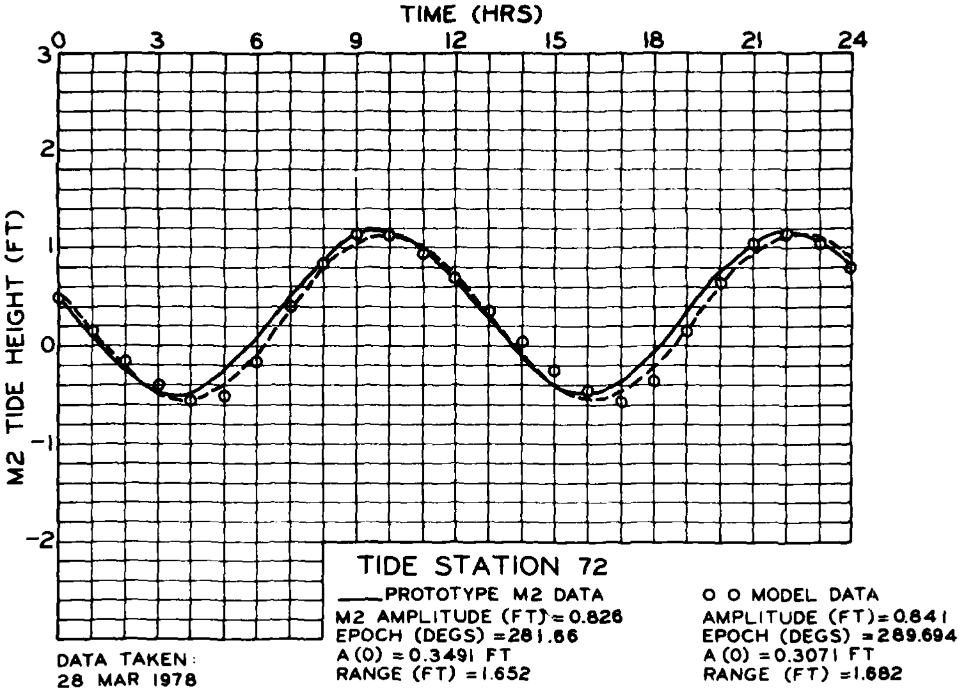




Plate B30. Model/prototype tide height comparison, sta 69 and 70



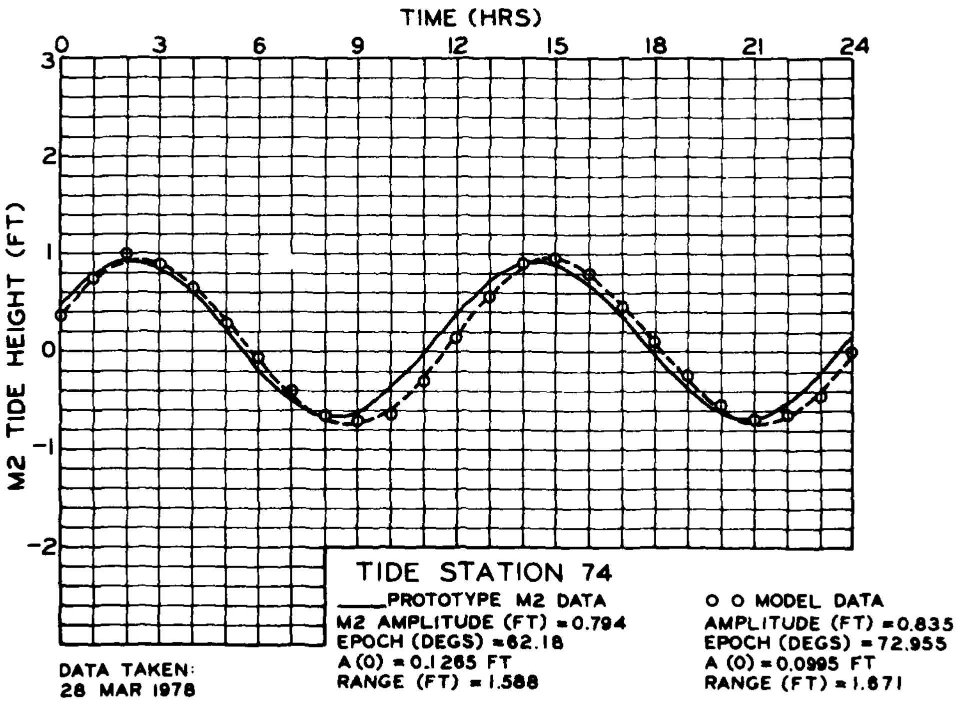




Plate B31. Model/prototype tide height comparison, sta 72 and 74

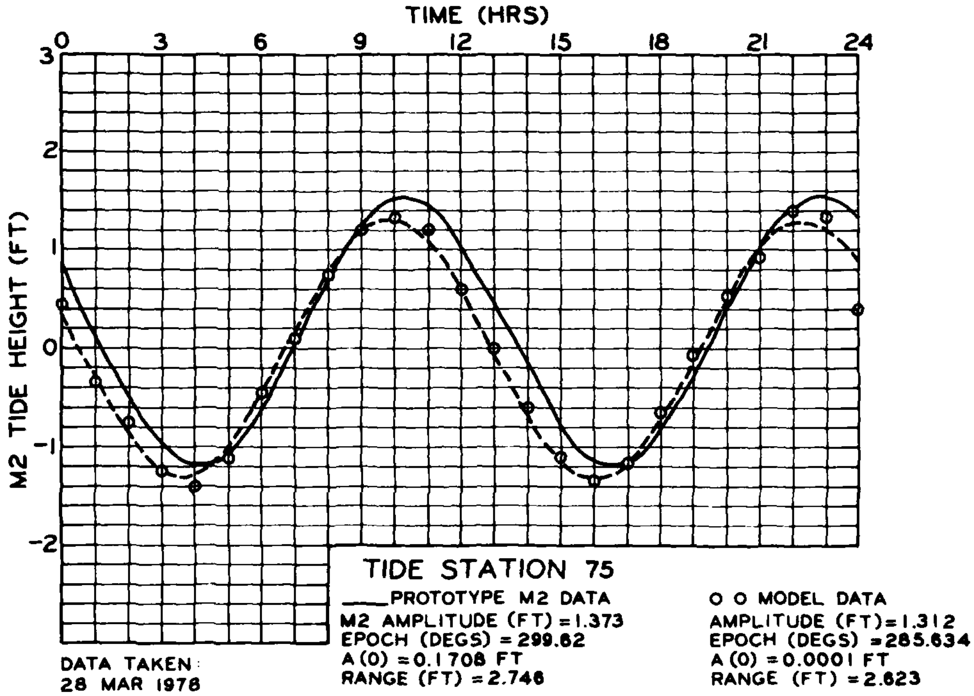



Plate B32. Model/prototype tide height comparison, sta 75

# APPENDIX C

## VELOCITY VERIFICATION DATA

Comparison of Model and Prototype Velocities for the $M_2$ Constituent at Selected Velocity Stations

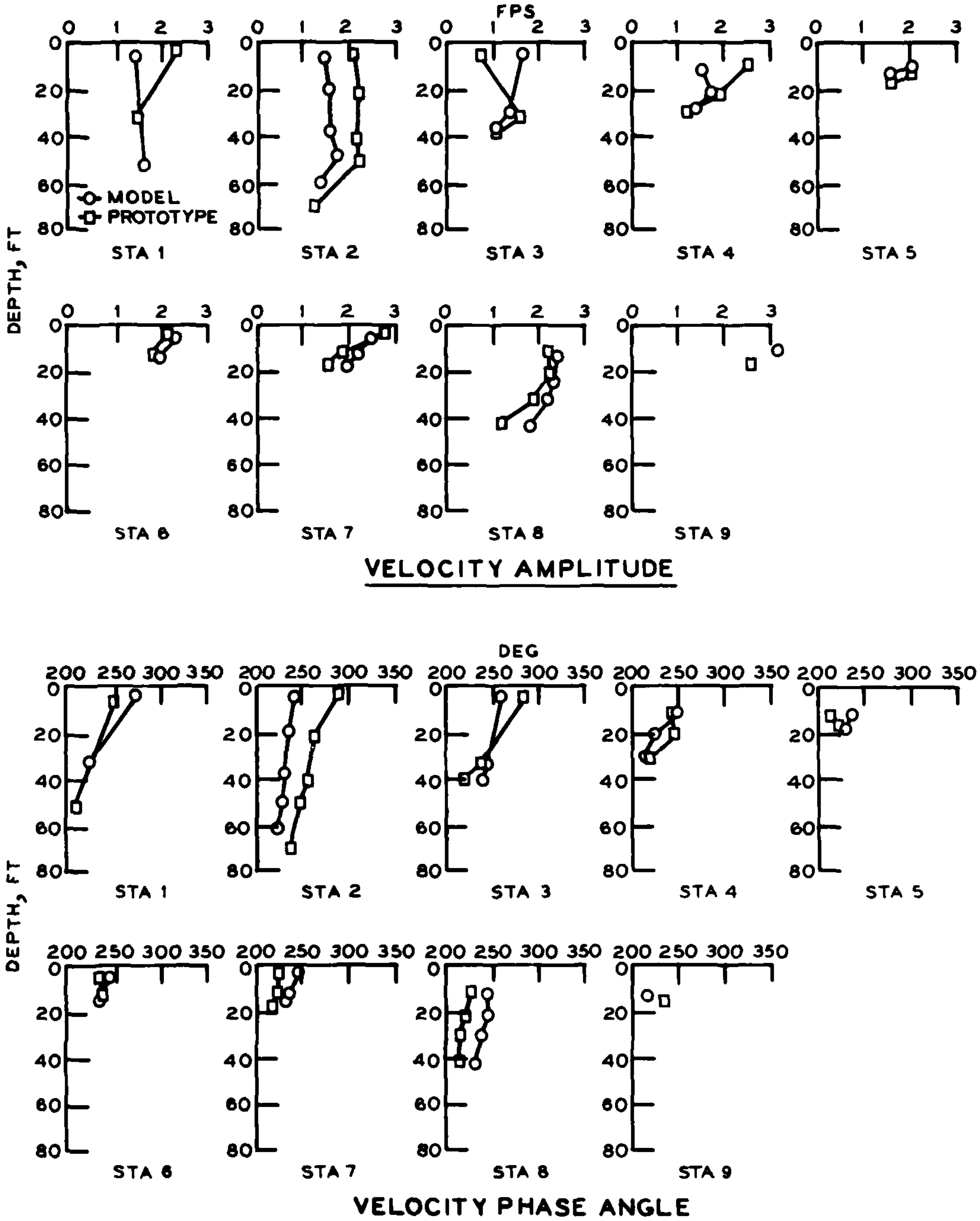



Plate C1. Model/prototype velocity comparison, Range CB00, Test 20

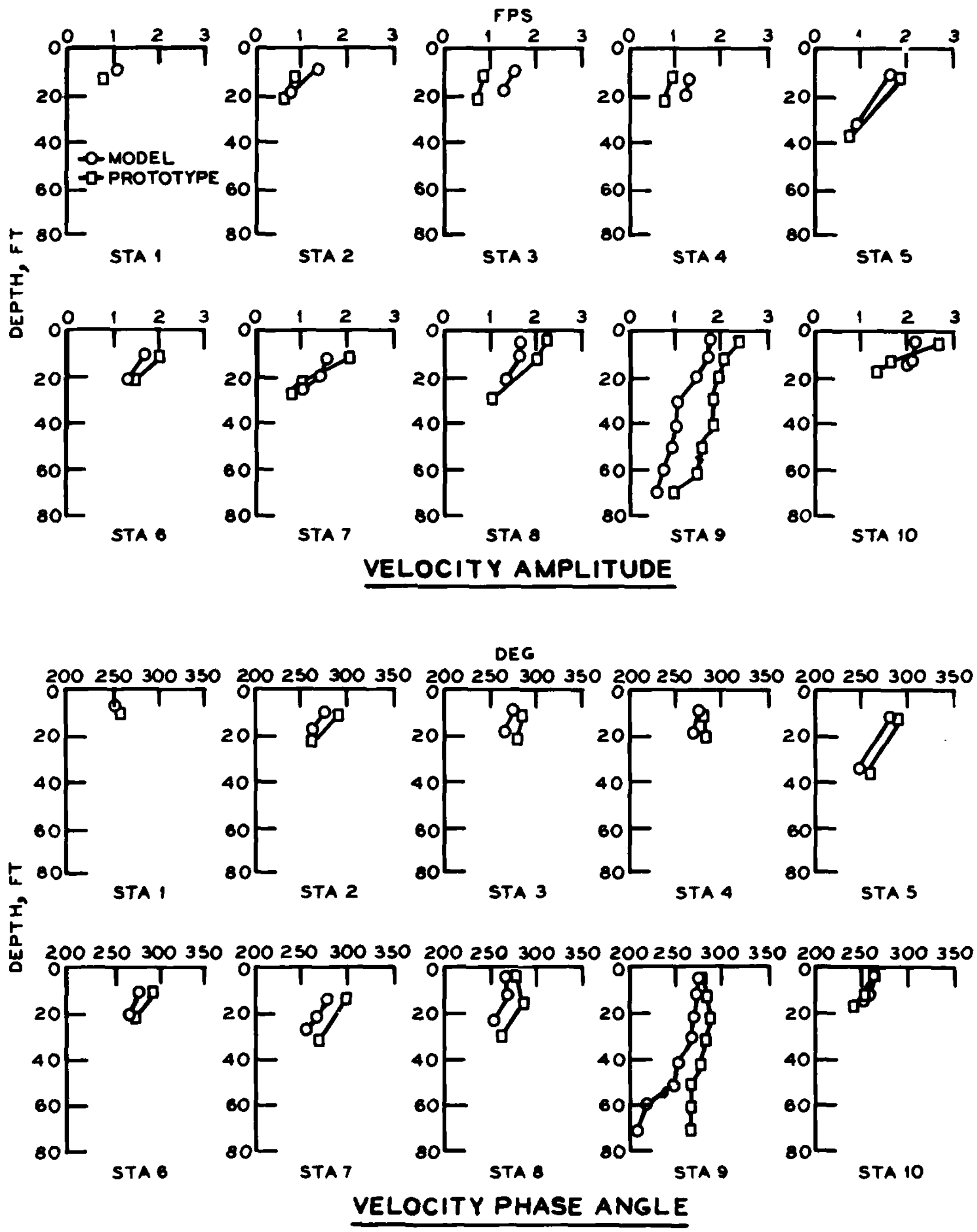



Plate C2. Model/prototype velocity comparison, Range CB01, Test 20

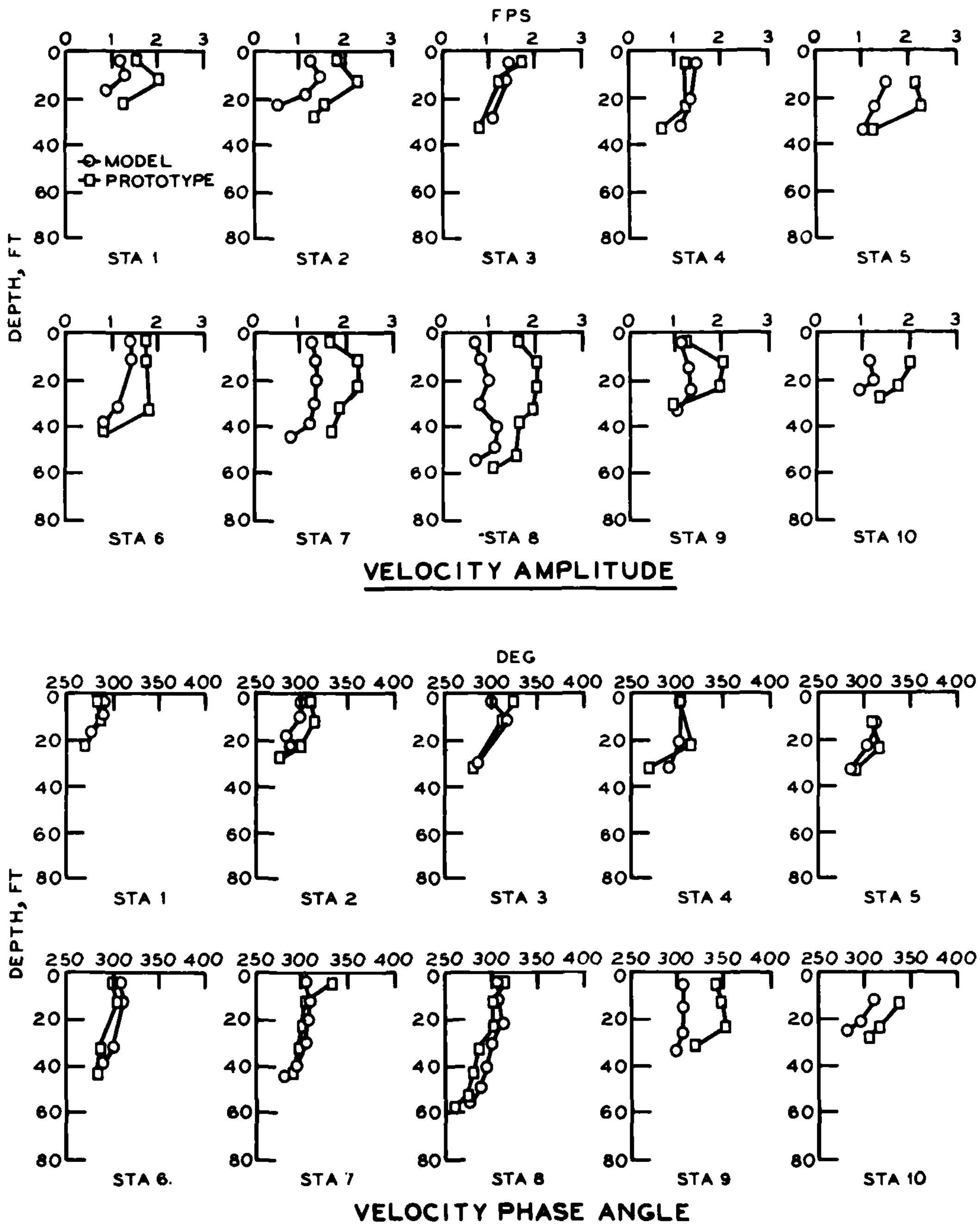



Plate C3. Model/prototype velocity comparison, Range CB02, Test 20

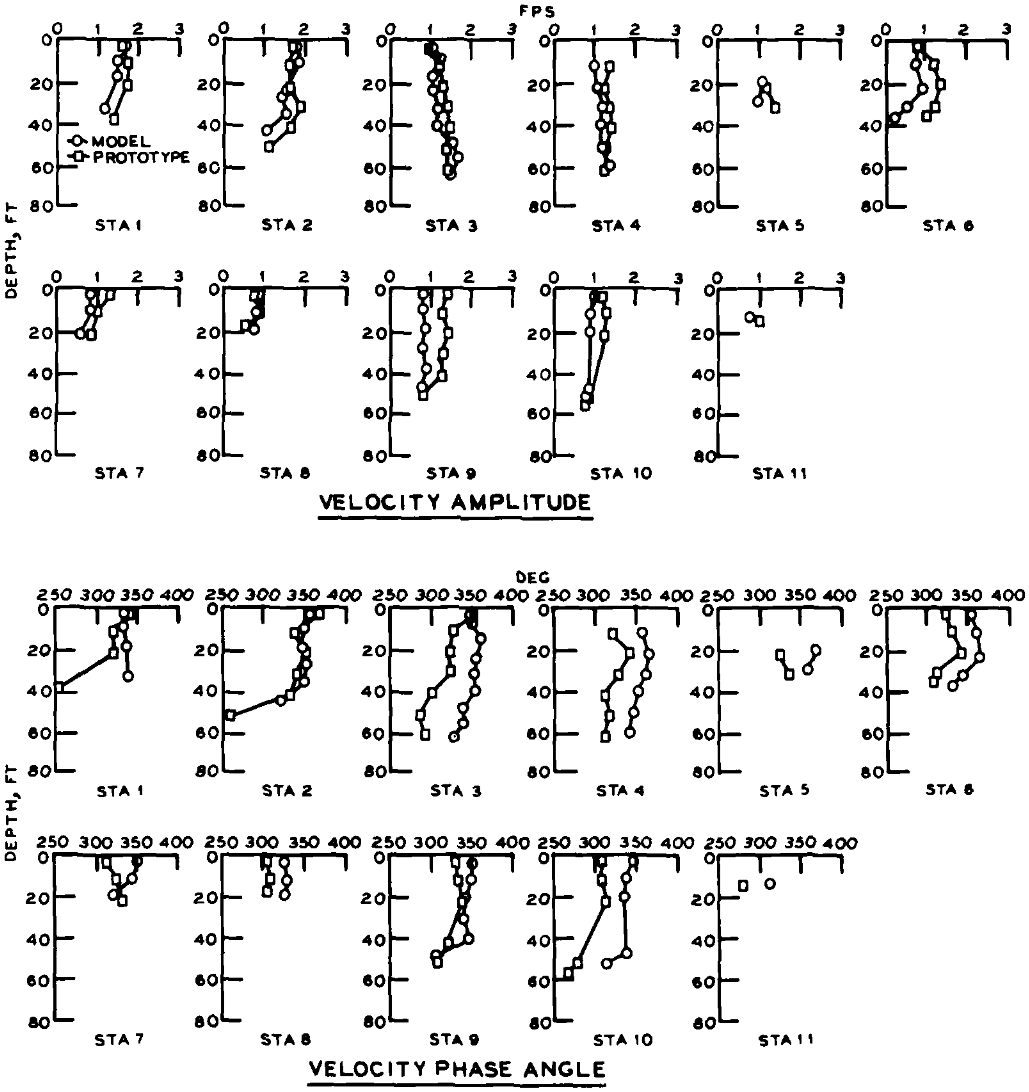



Plate C4. Model/prototype velocity comparison, Range CB03, Test 20

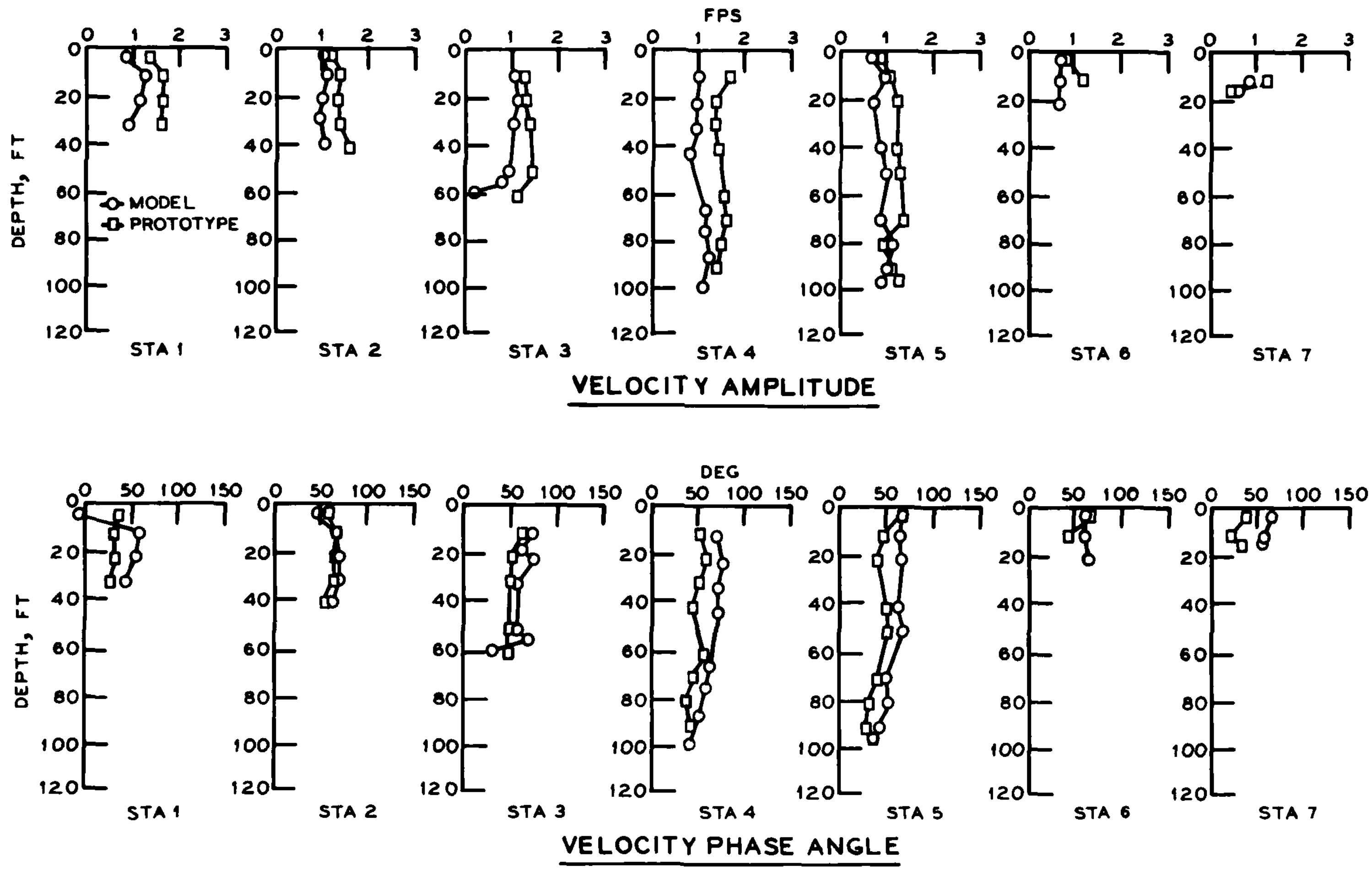



Plate C5. Model/prototype velocity comparison, Range CB04, Test 20

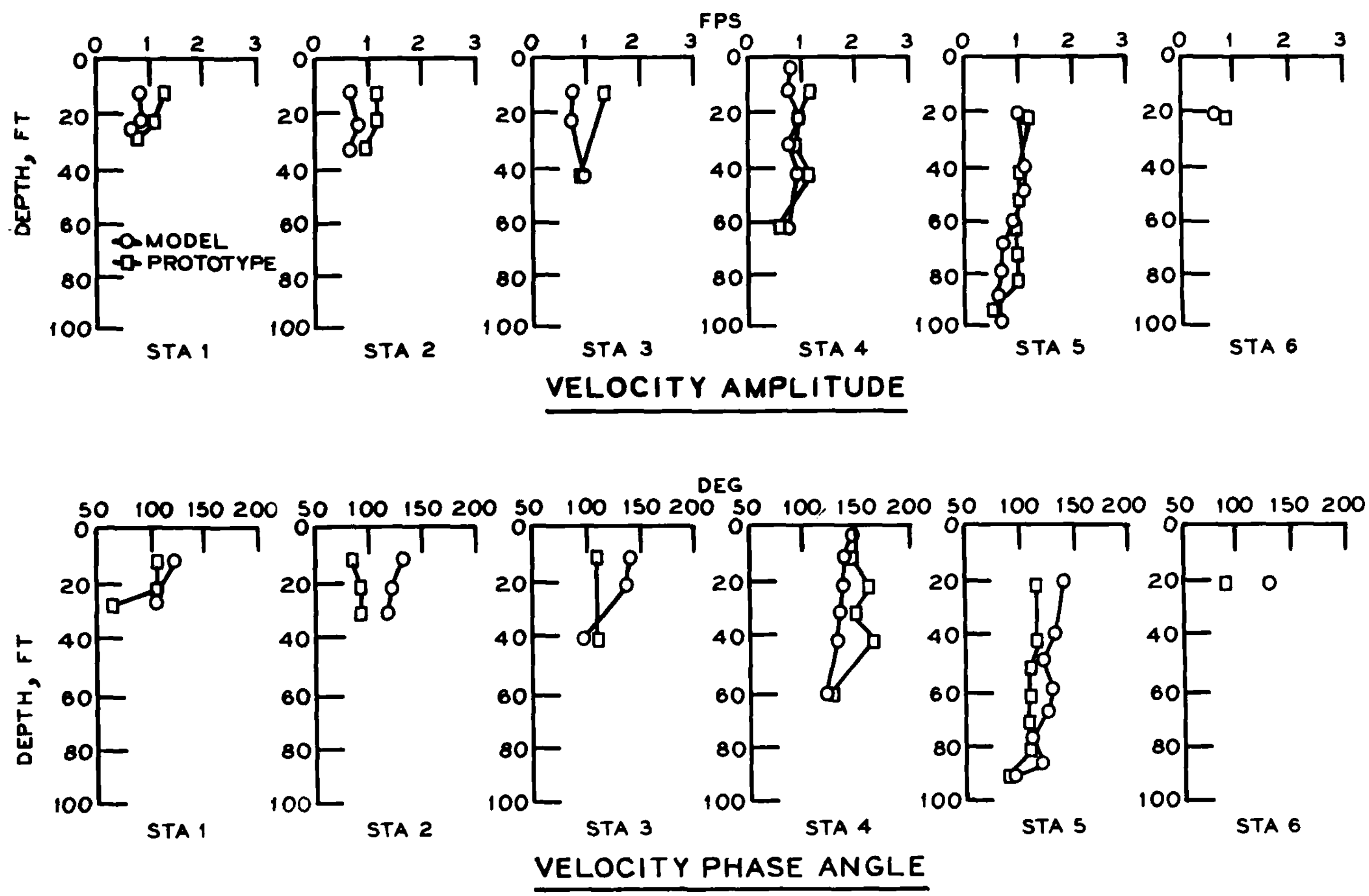



Plate C6. Model/prototype velocity comparison, Range CB05, Test 20

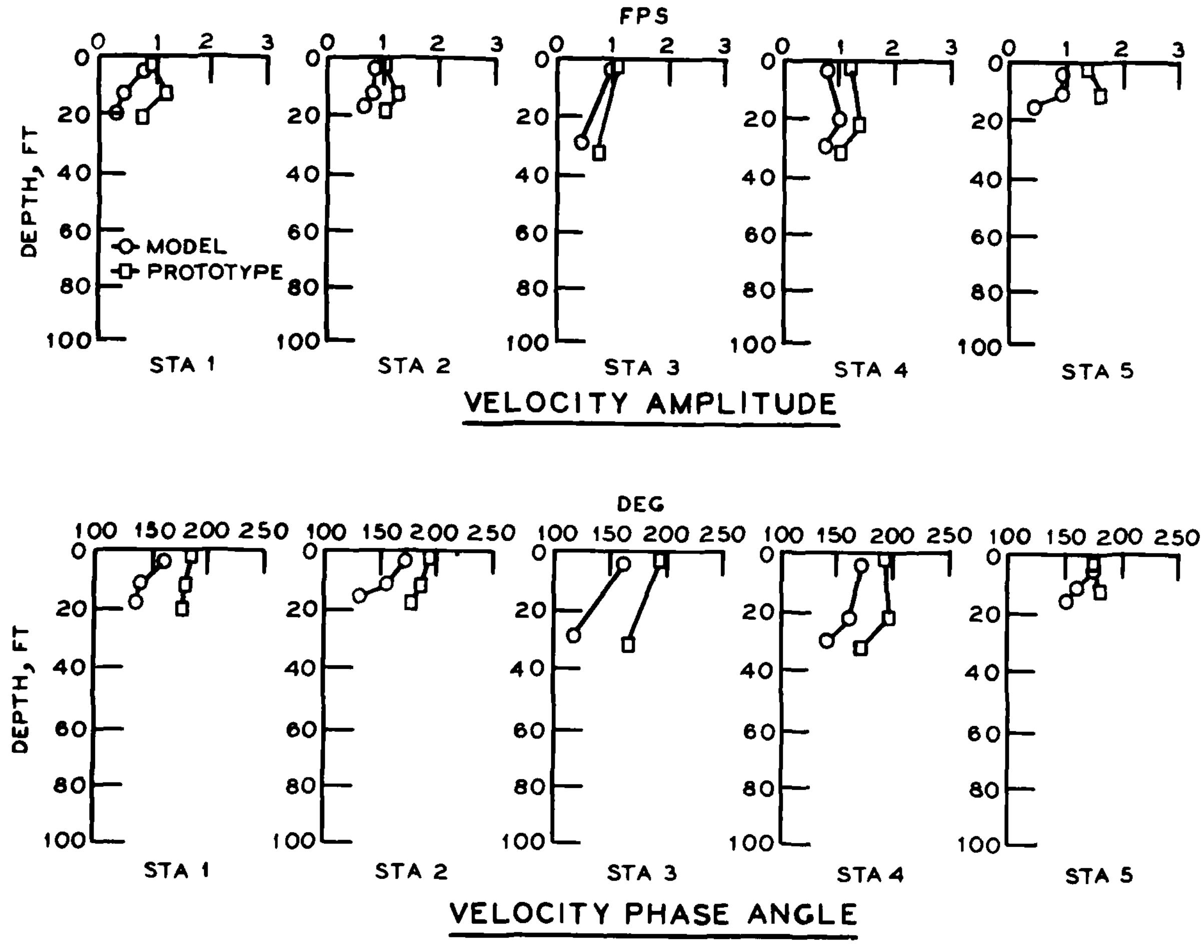



Plate C7. Model/prototype velocity comparison, Range CB06, Test 20

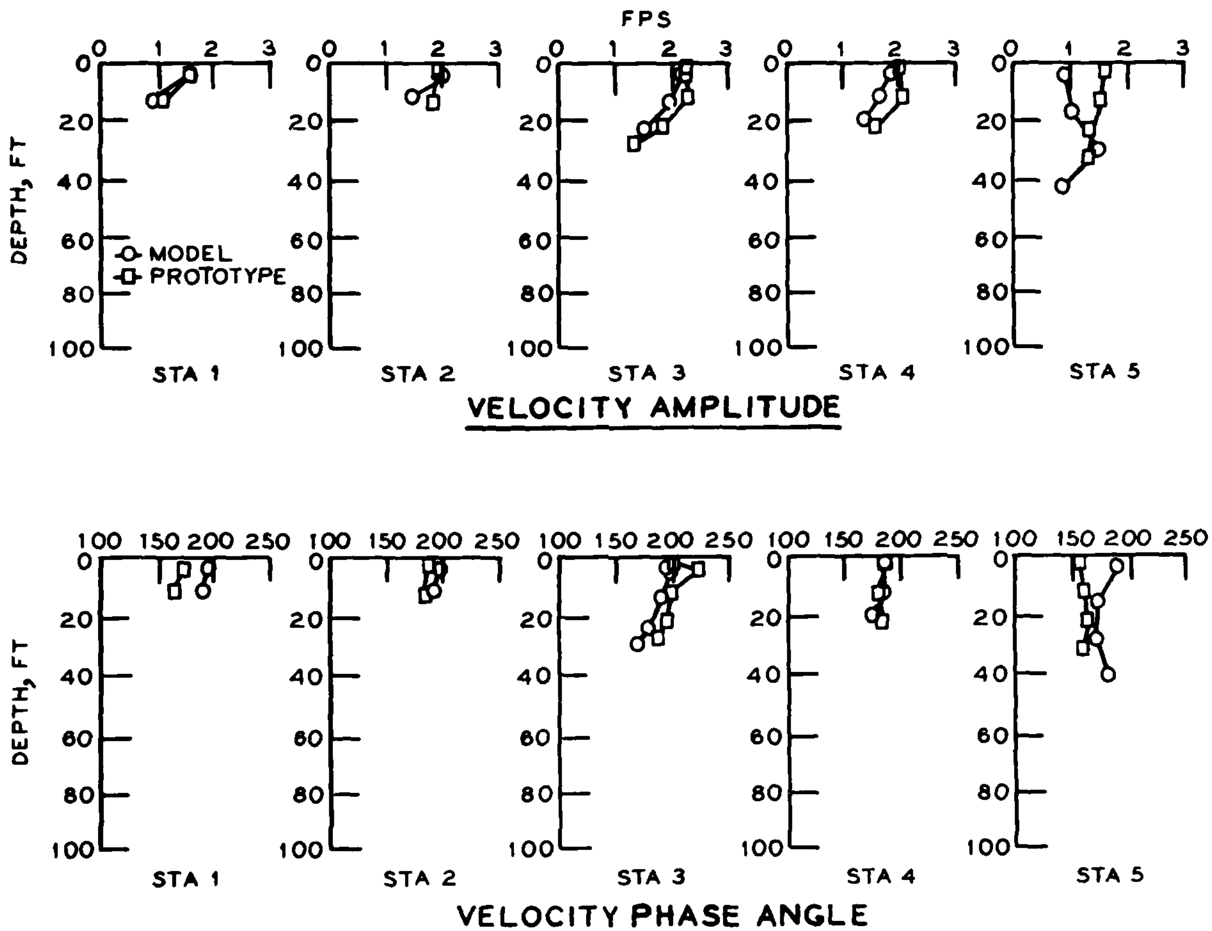



Plate C8. Model/prototype velocity comparison, Range CB07, Test 20

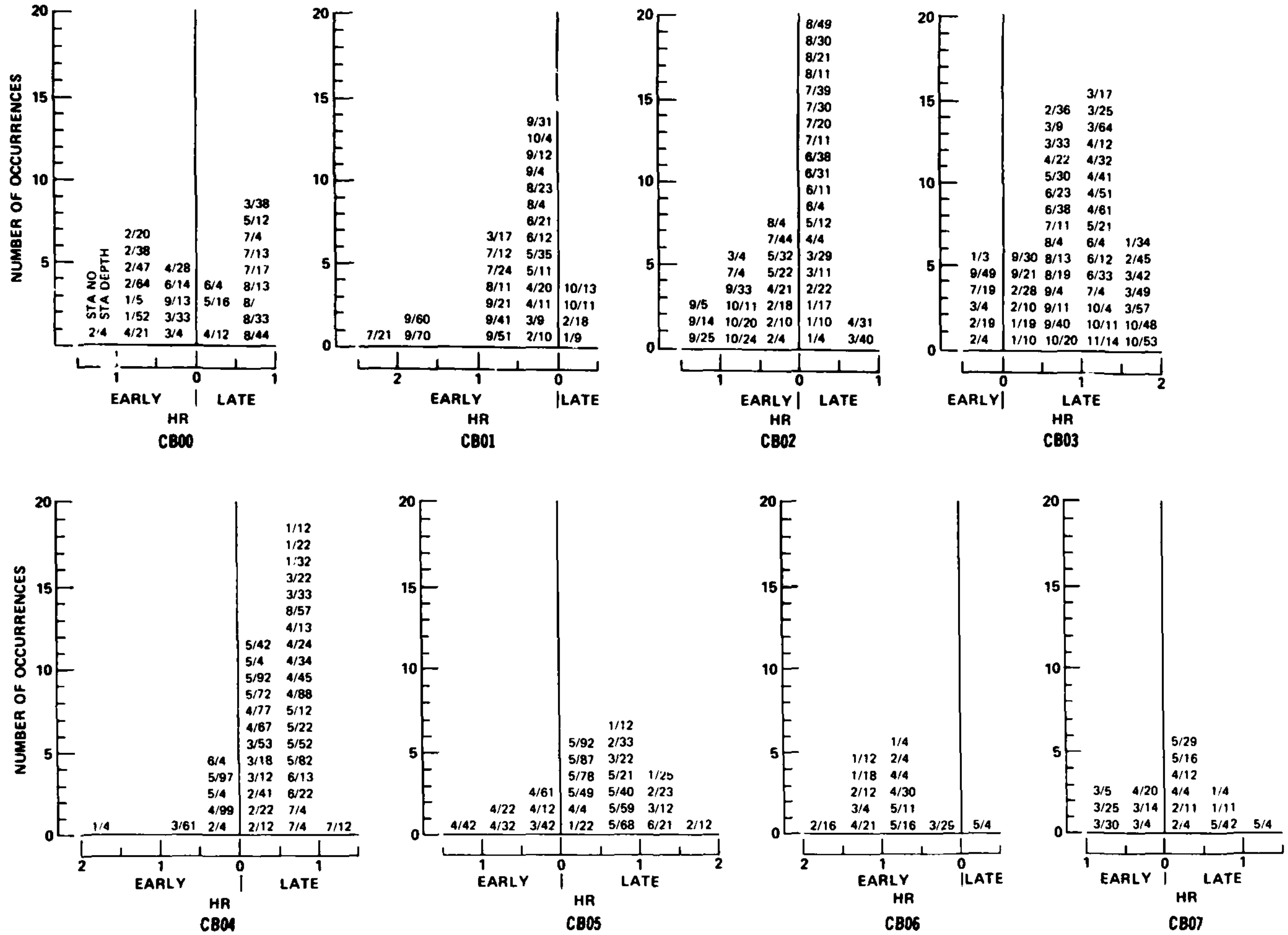



Plate C9. Velocity arrival time differences, Test 20

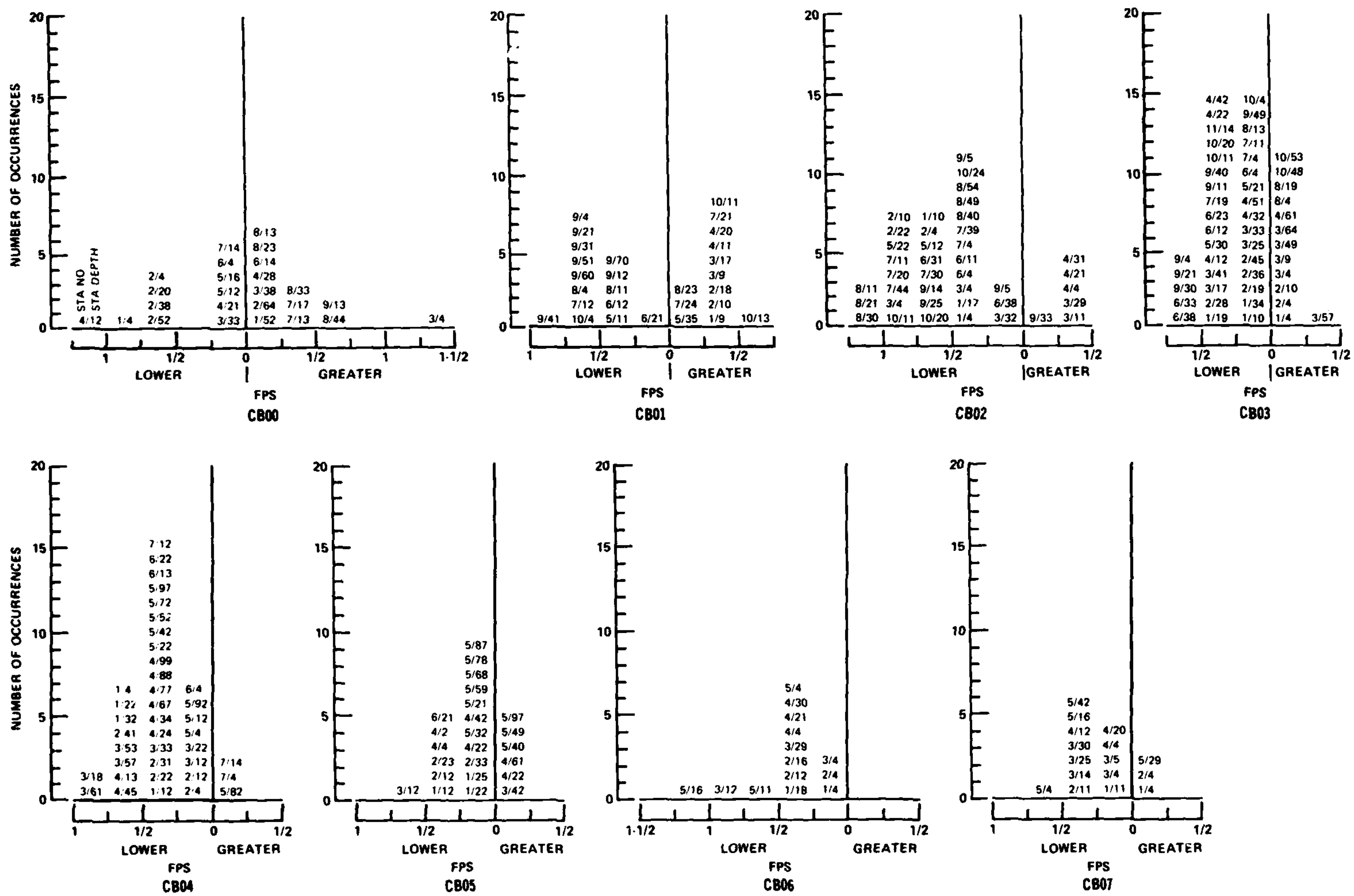
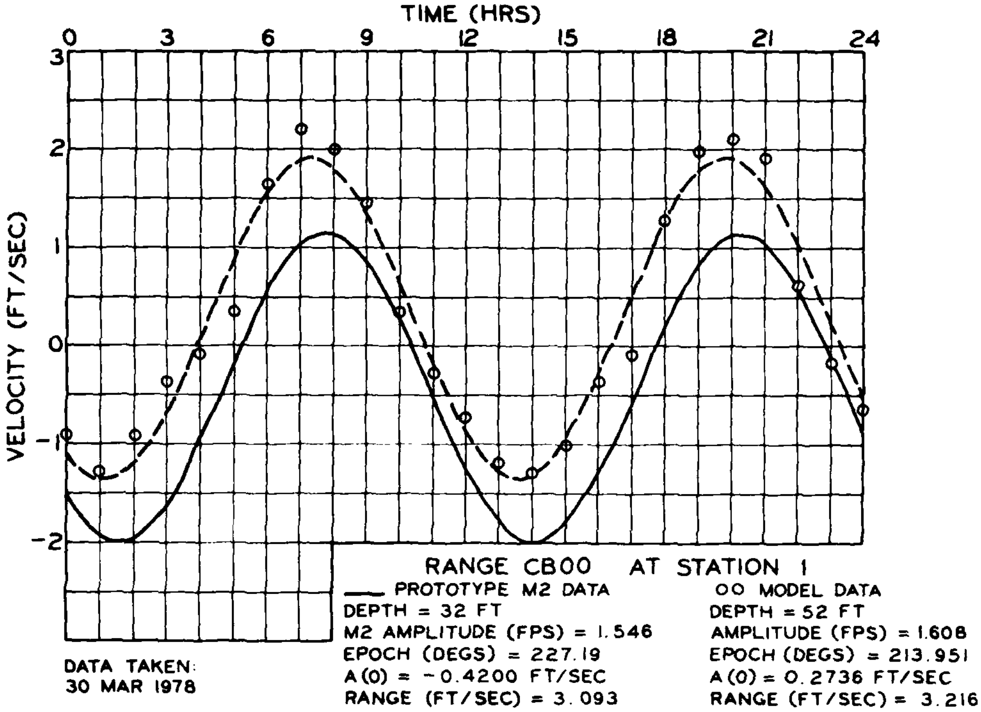



Plate C10. Velocity amplitude differences, Test 20



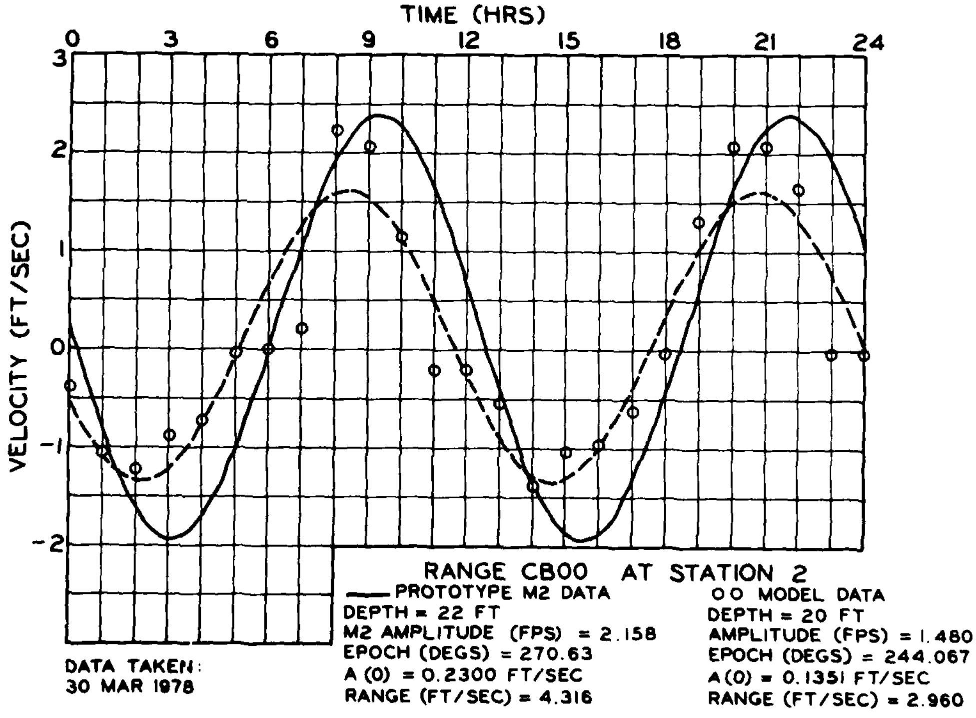
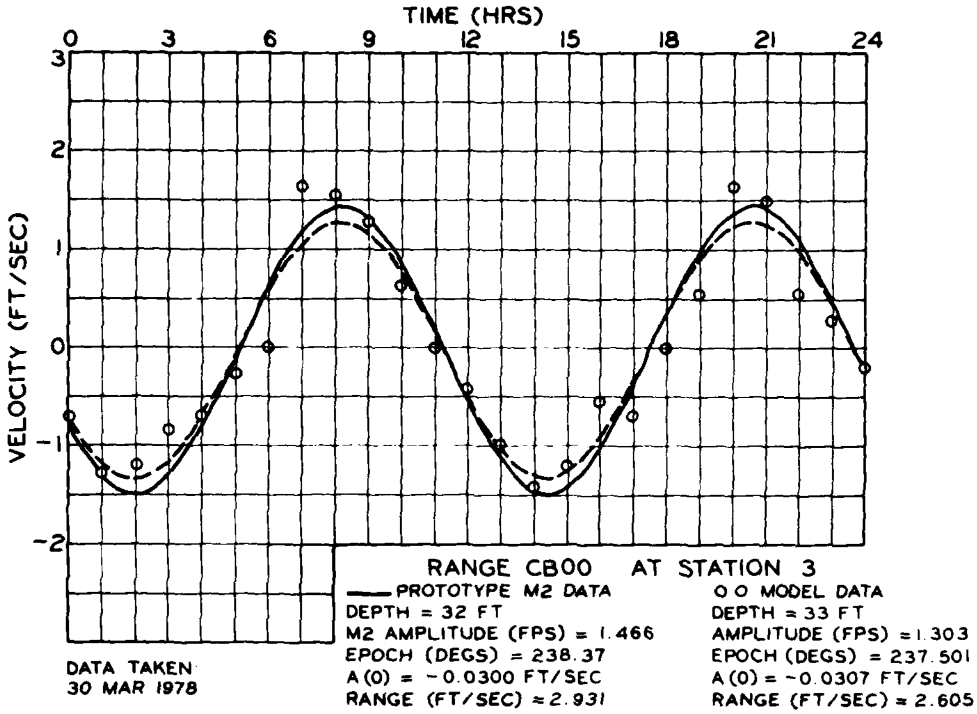




Plate C11. Model/prototype velocity comparison, Range CB00, sta 1 and 2



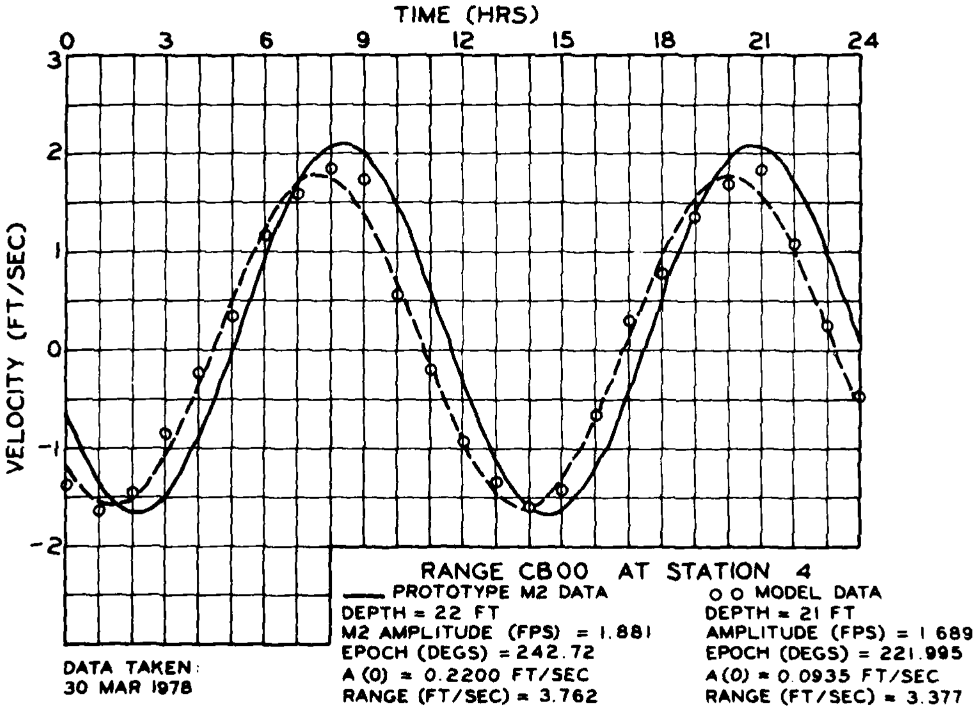




Plate C12. Model/prototype velocity comparison,
Range CBOO, sta 3 and 4

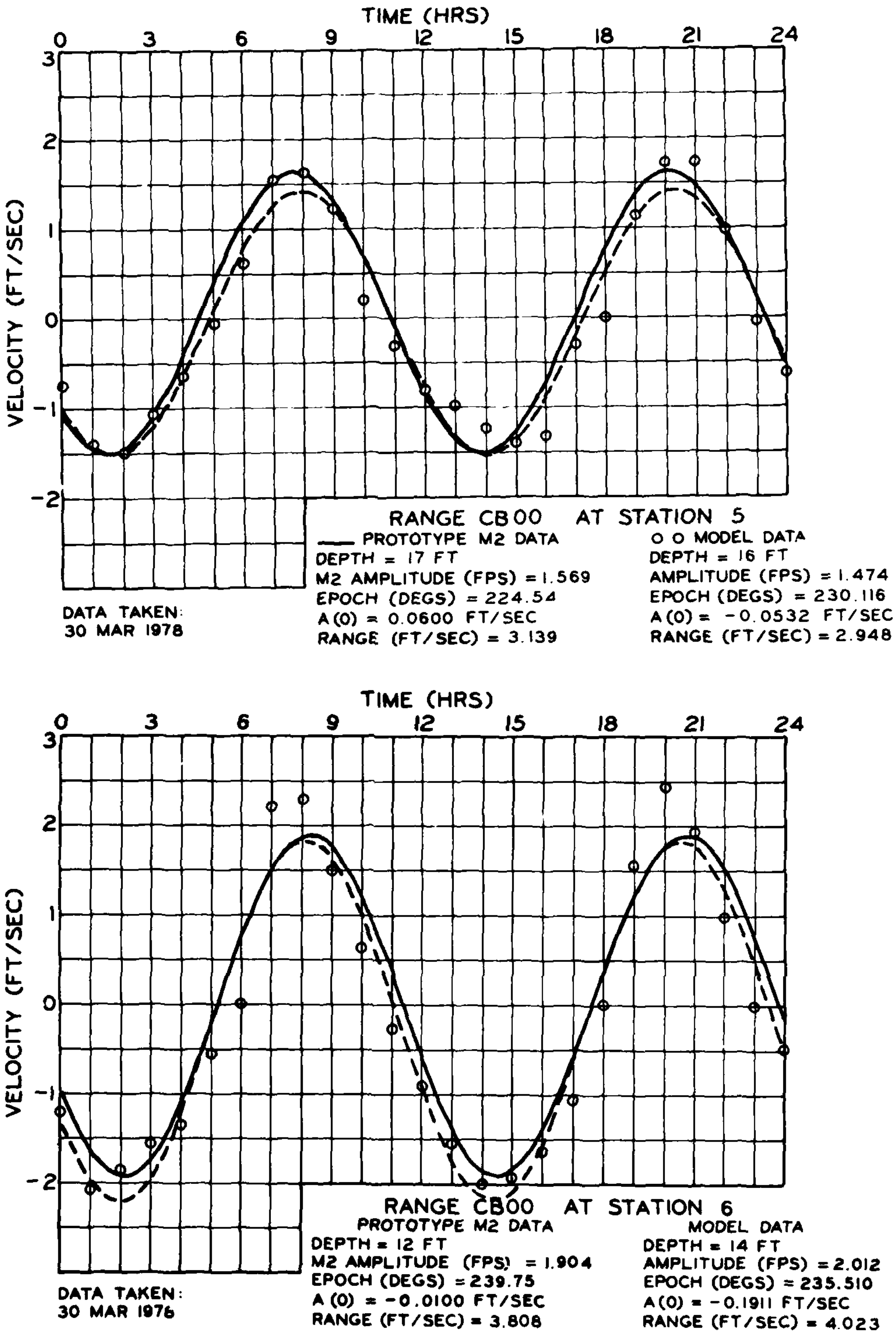
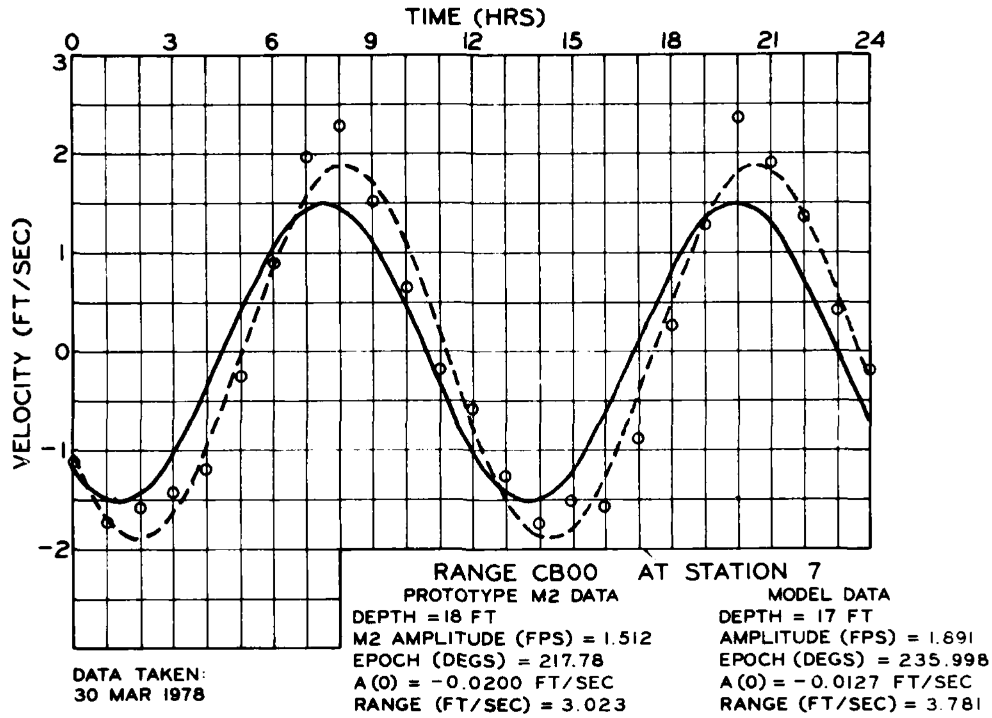



Plate C13. Model/prototype velocity comparison,
Range CB00, sta 5 and 6



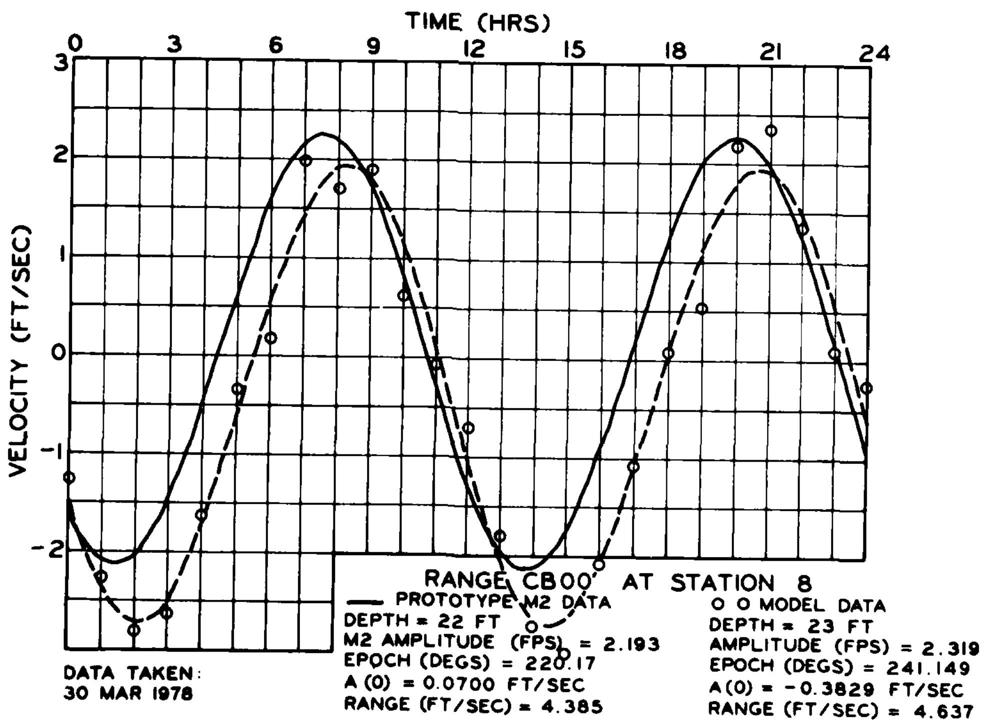
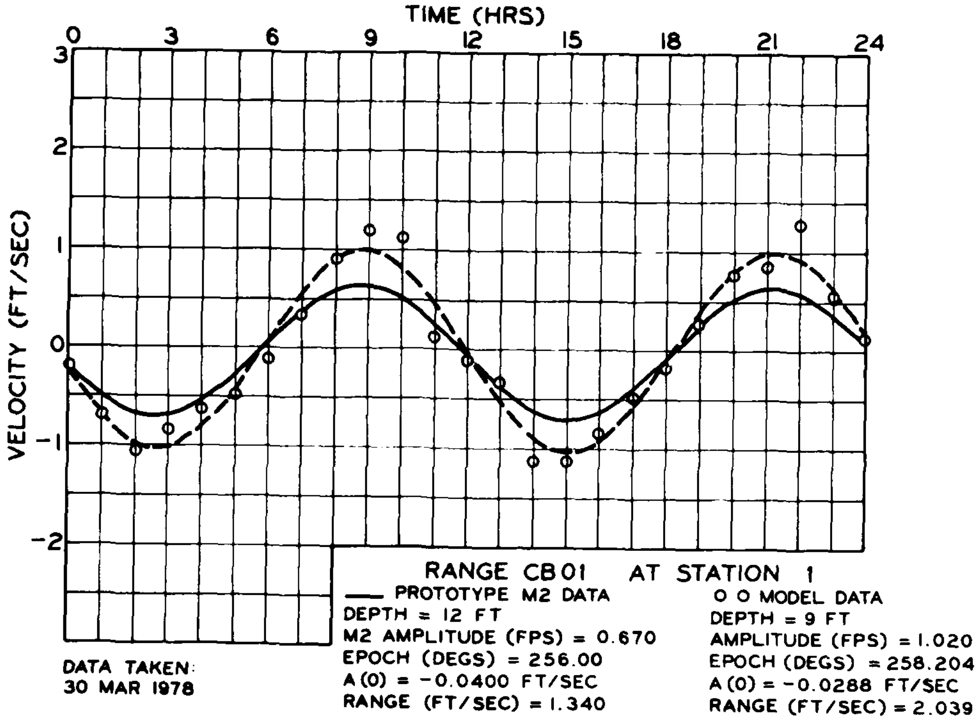




Plate C14. Model/prototype velocity comparison,
Range CB00, sta 7 and 8



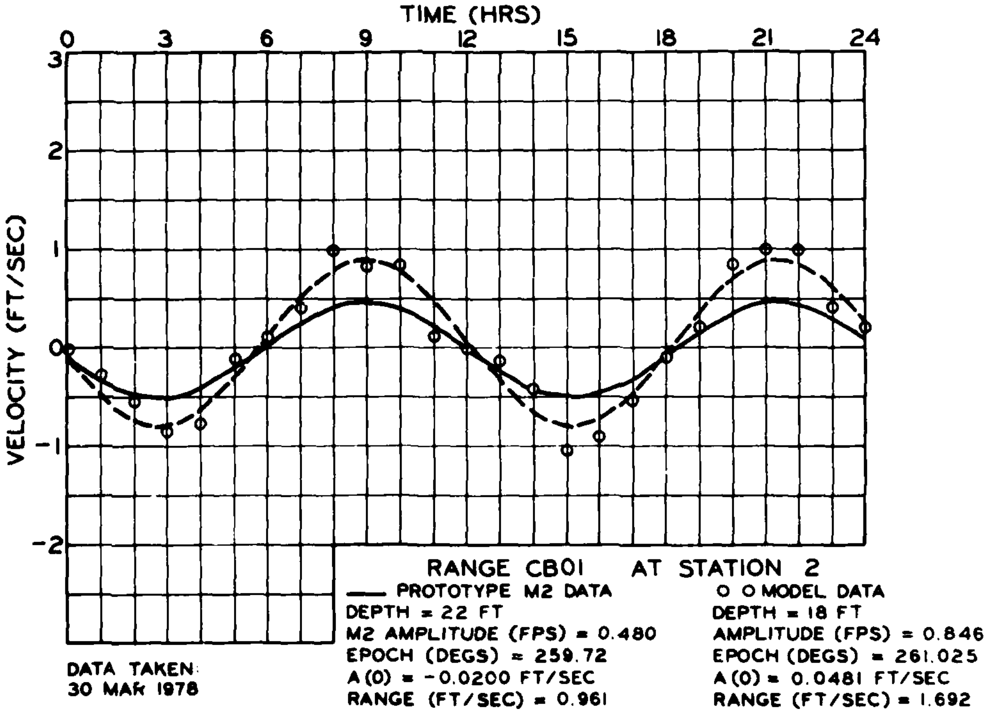
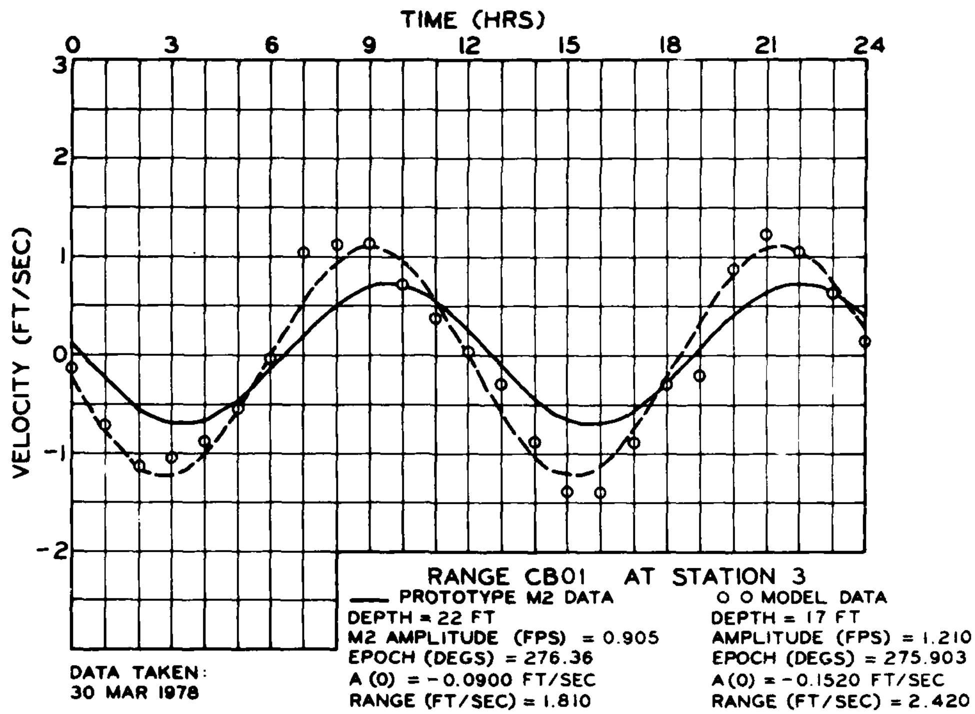




Plate C15. Model/prototype velocity comparison, Range CB01, sta 1 and 2



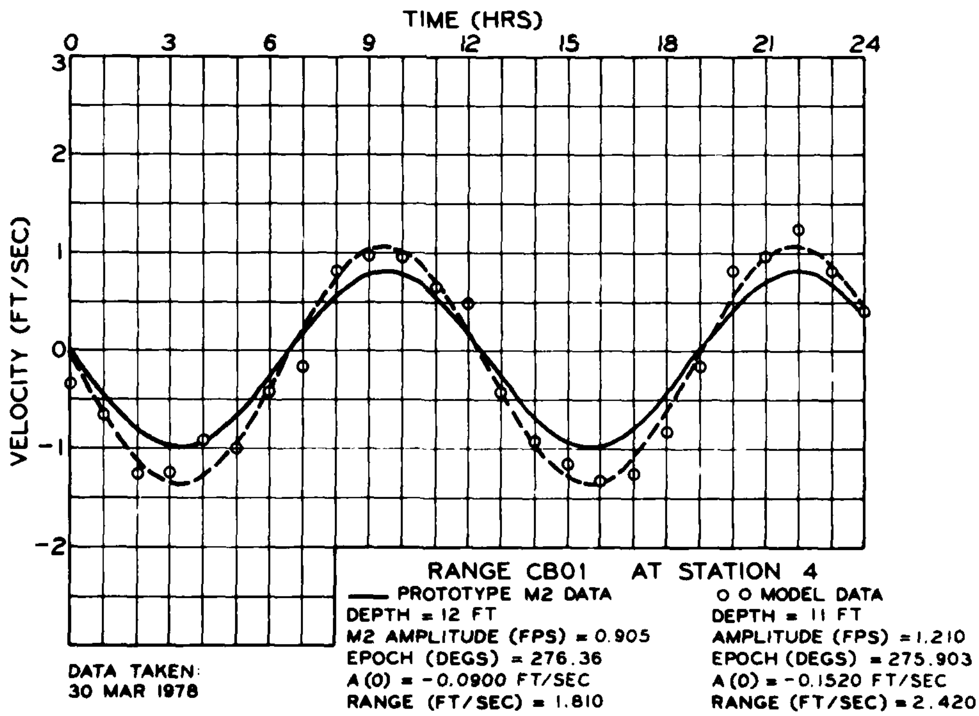
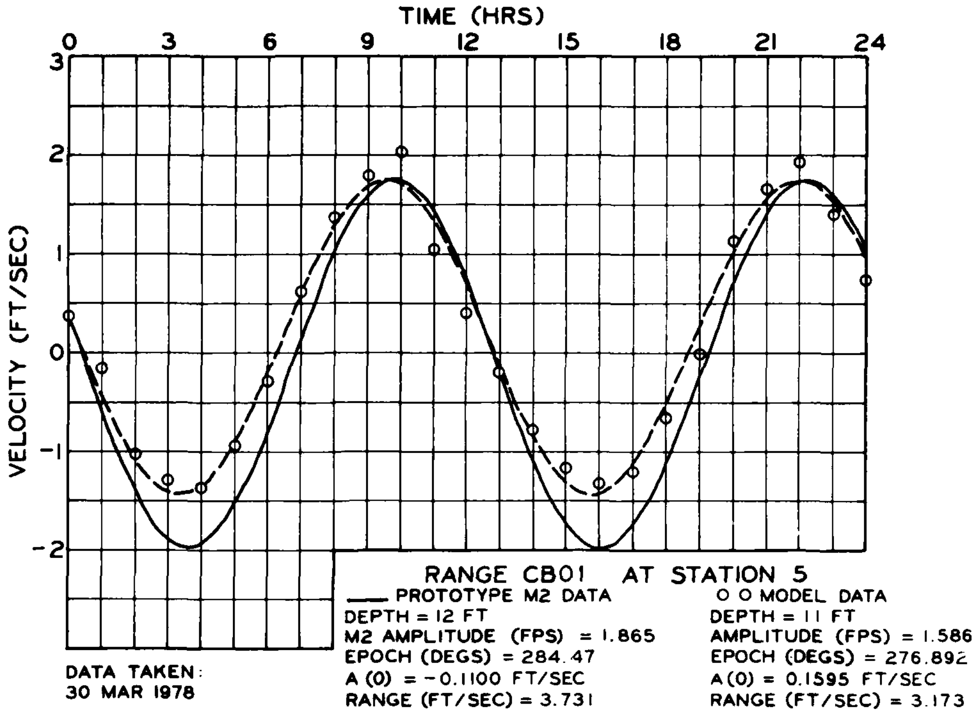




Plate C16. Model/prototype velocity comparison, Range CB01, sta 3 and 4



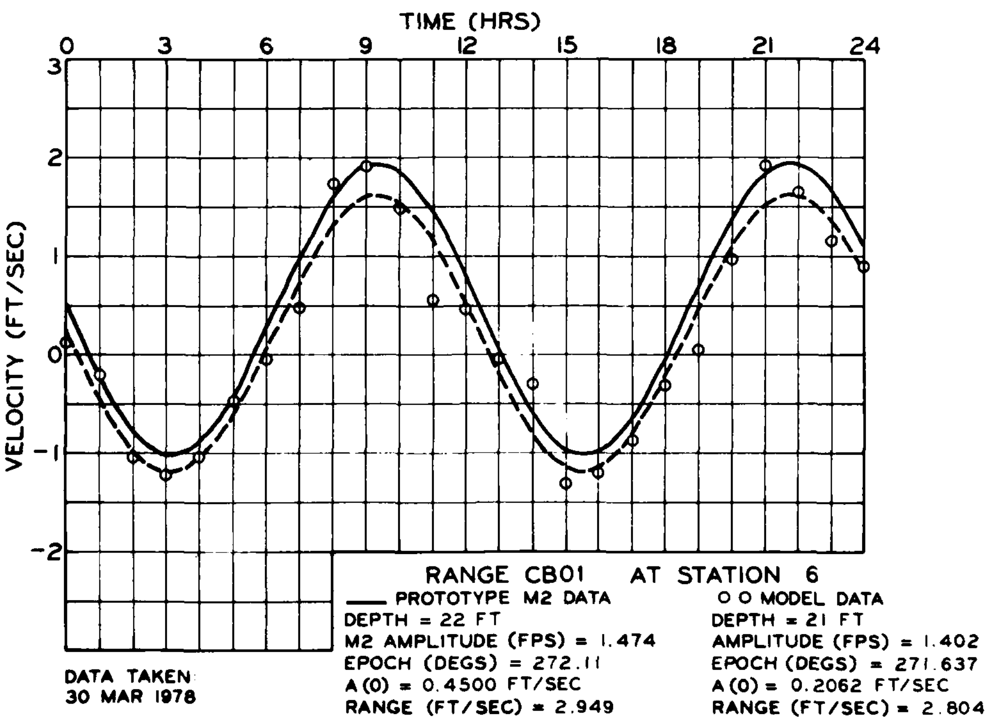
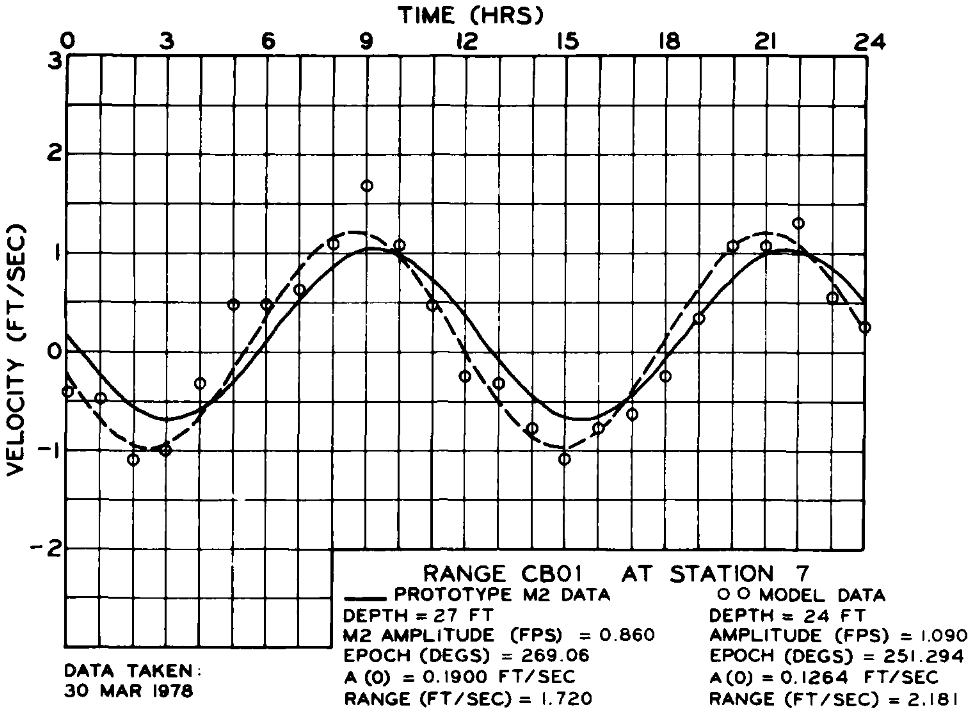




Plate C17. Model/prototype velocity comparison, Range CB01, sta 5 and 6



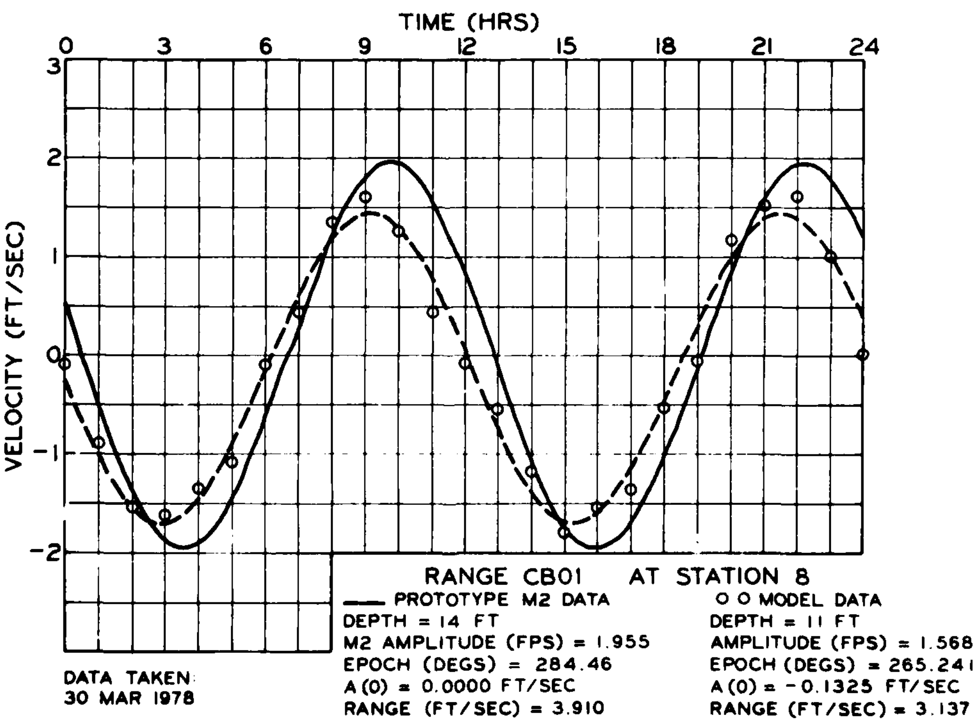
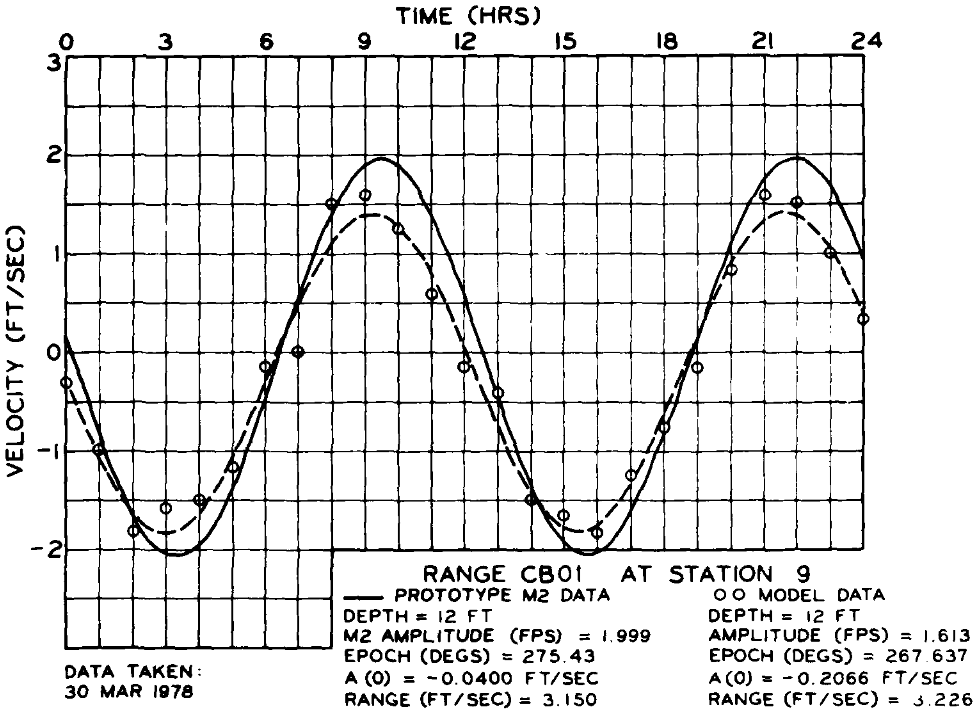




Plate C18. Model/prototype velocity comparison, Range CB01, sta 7 and 8



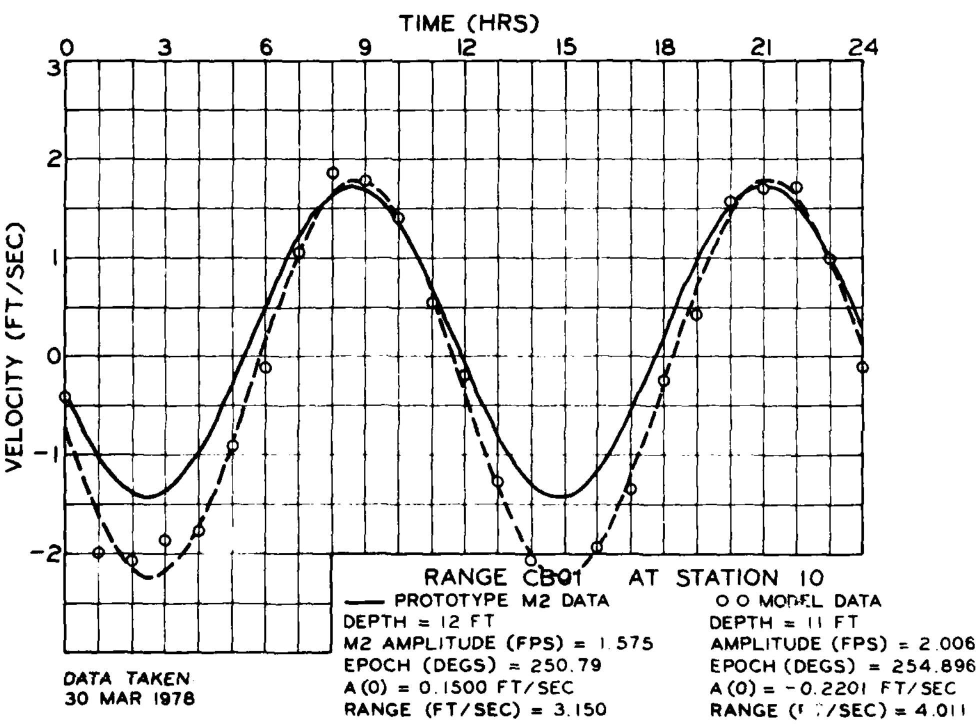
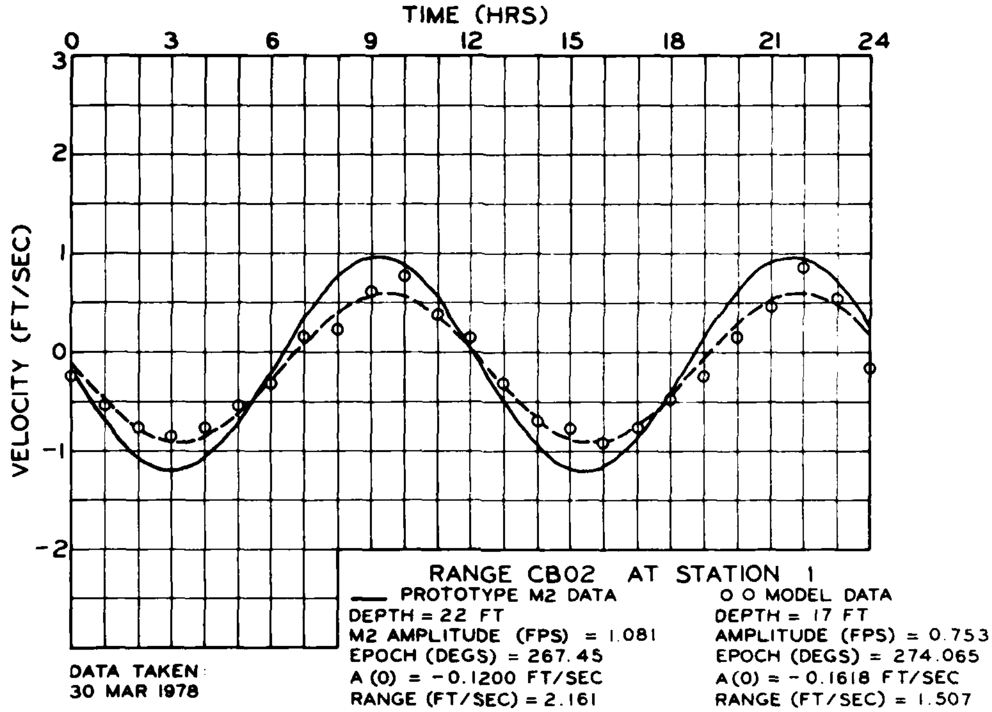




Plate C19. Model/prototype velocity comparison, Range CB01, sta 9 and 10



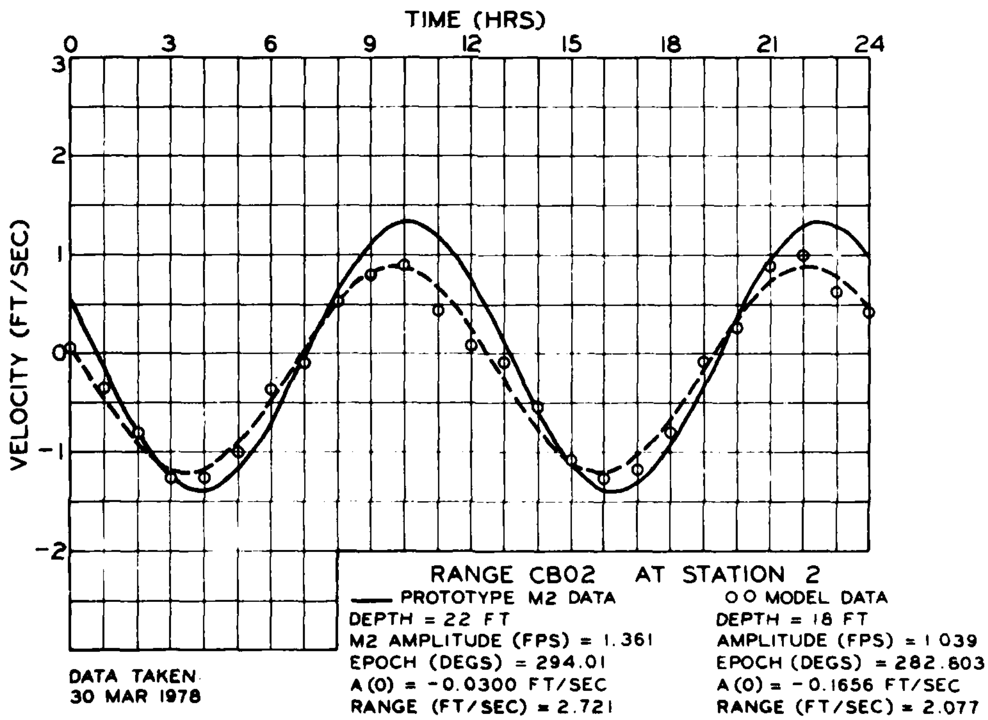
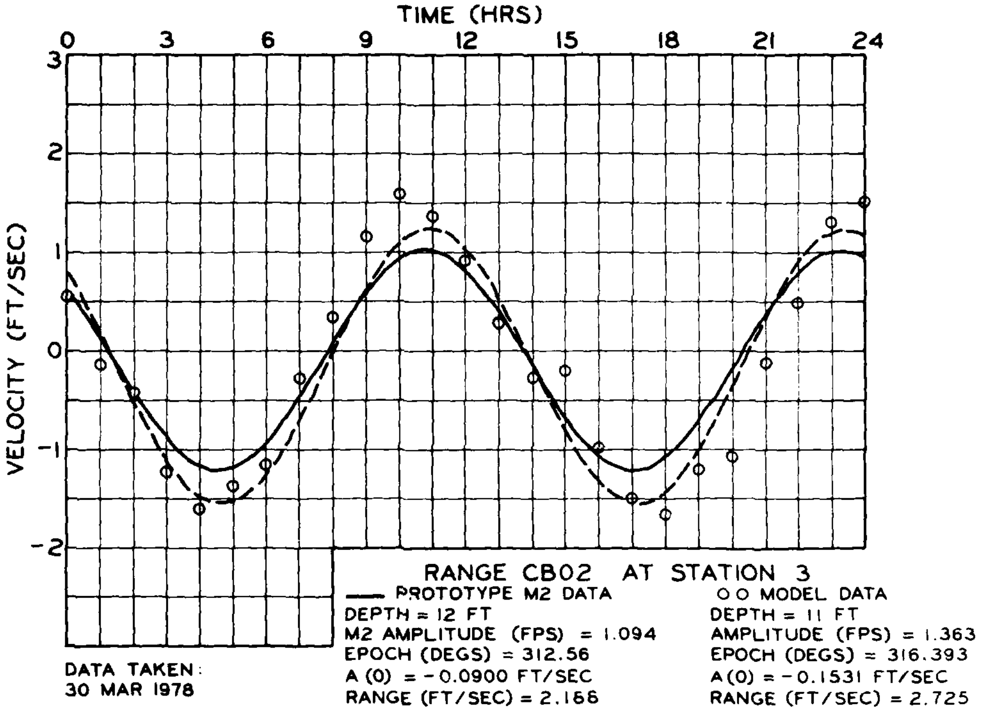




Plate C20. Model/prototype velocity comparison,
Range CB02, sta 1 and 2



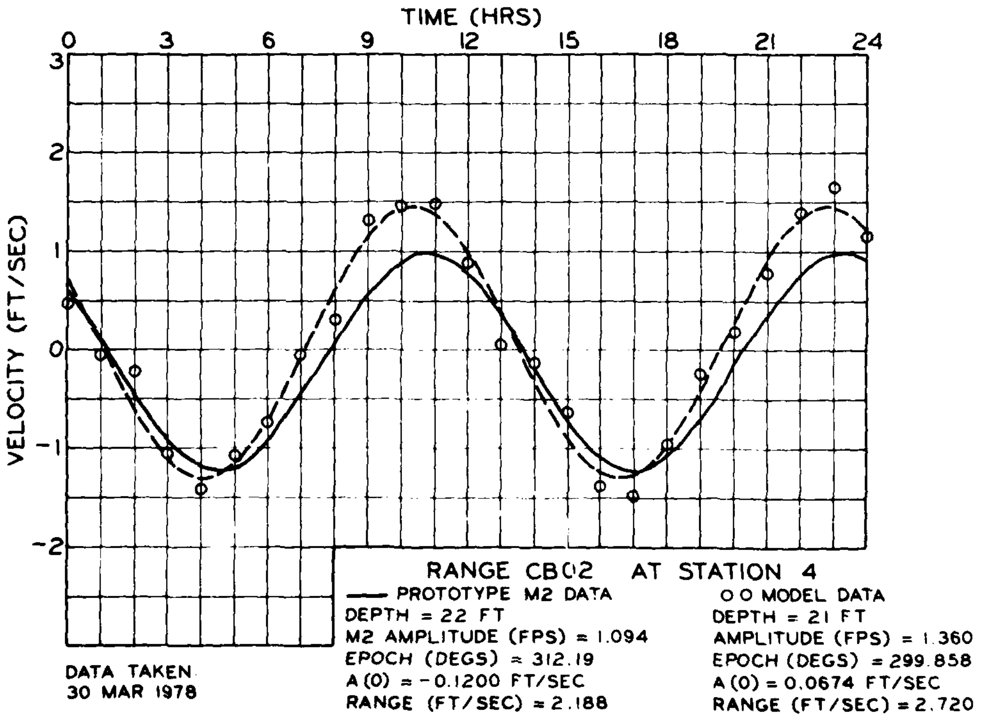
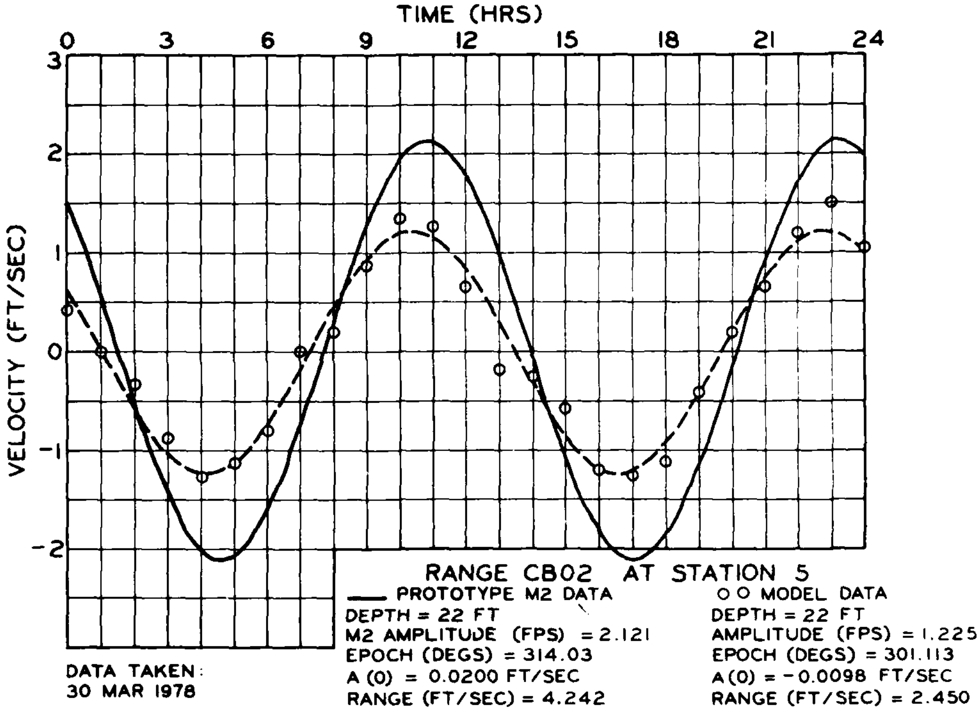




Plate C21. Model/prototype velocity comparison, Range CB02, sta 3 and 4



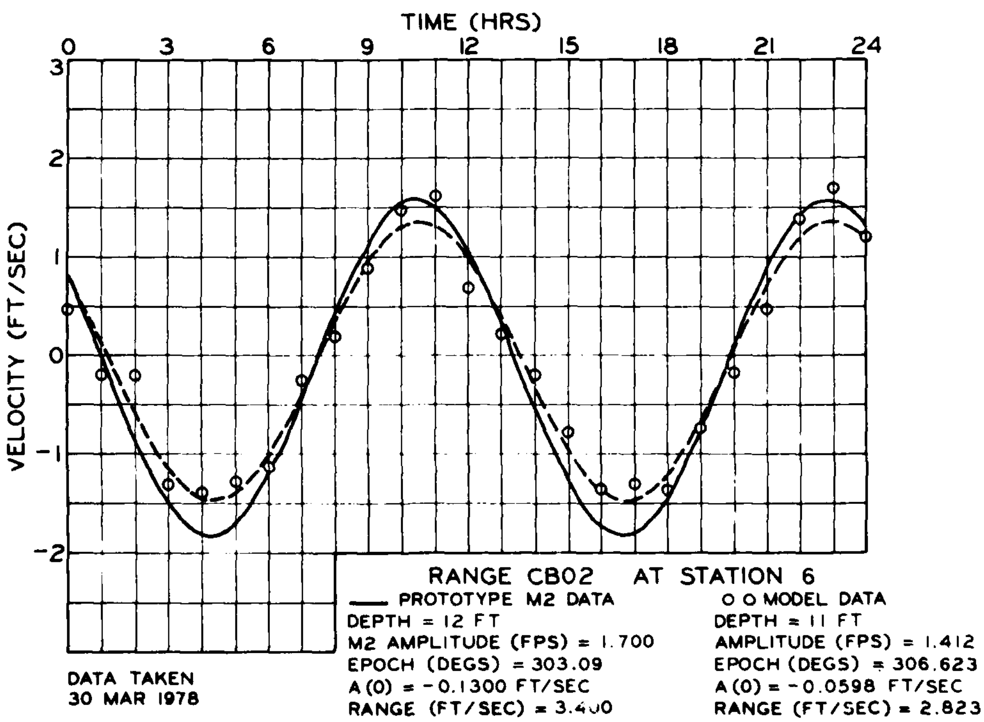




Plate C22. Model/prototype velocity comparison, Range CB02, sta 5 and 6

AD-A111 812 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
VERIFICATION OF THE CHESAPEAKE BAY MODEL.(U)
DEC 81 N W SCHEFFNER, L G CROSBY, D F BASTIAN
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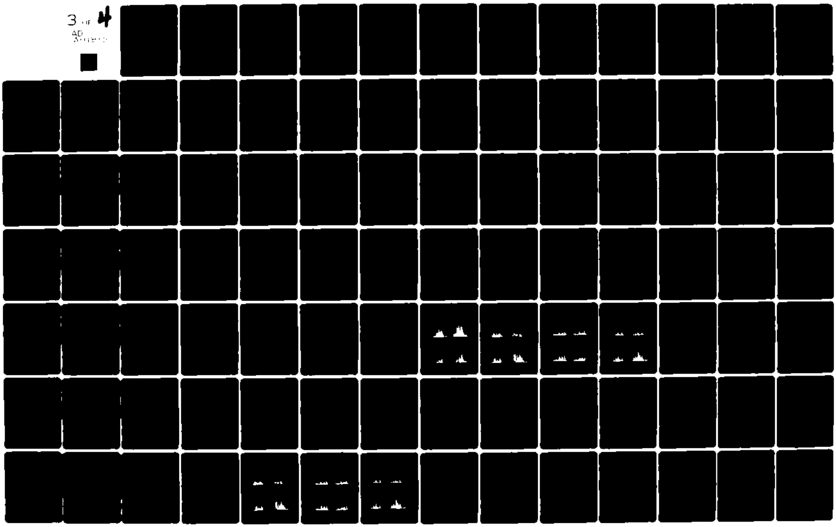

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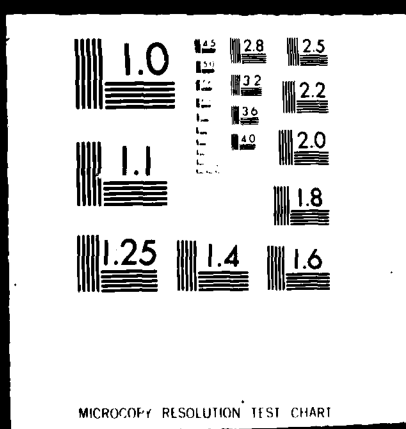
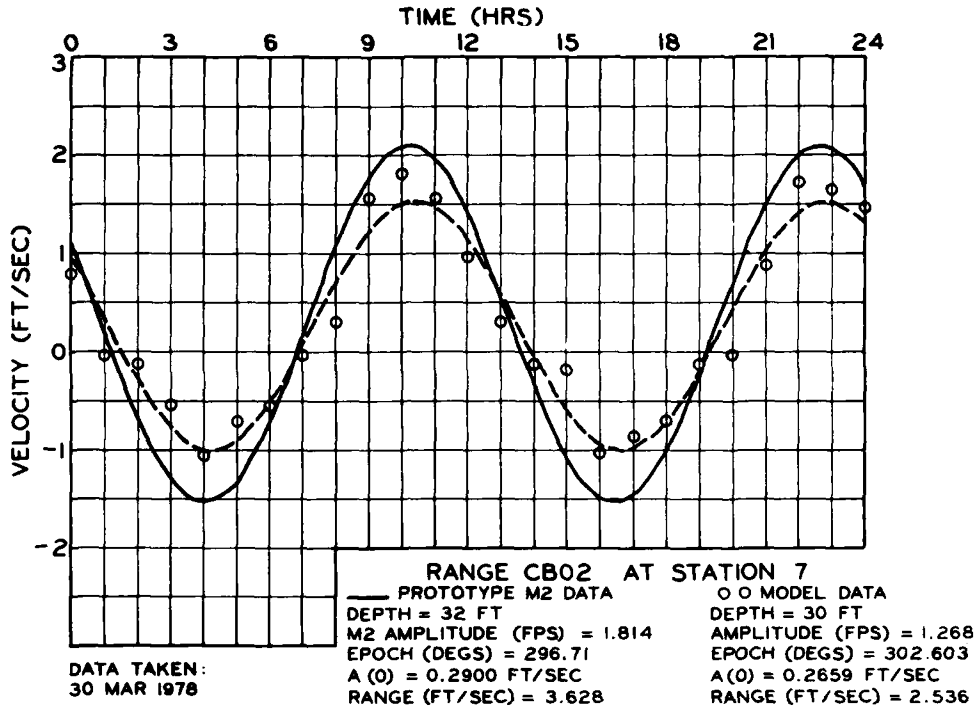




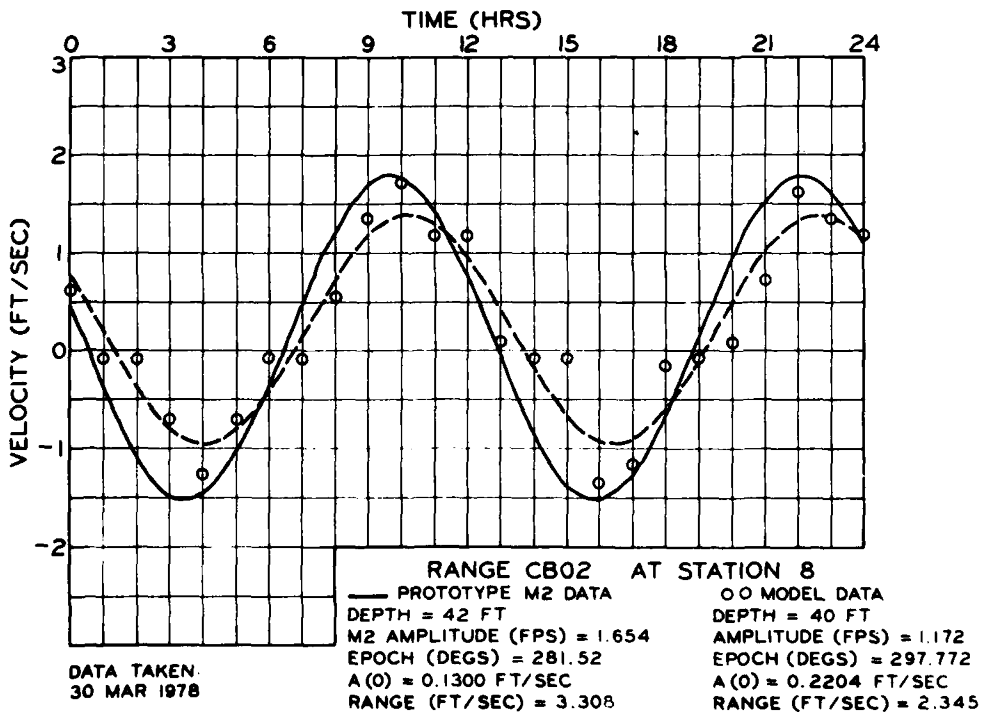
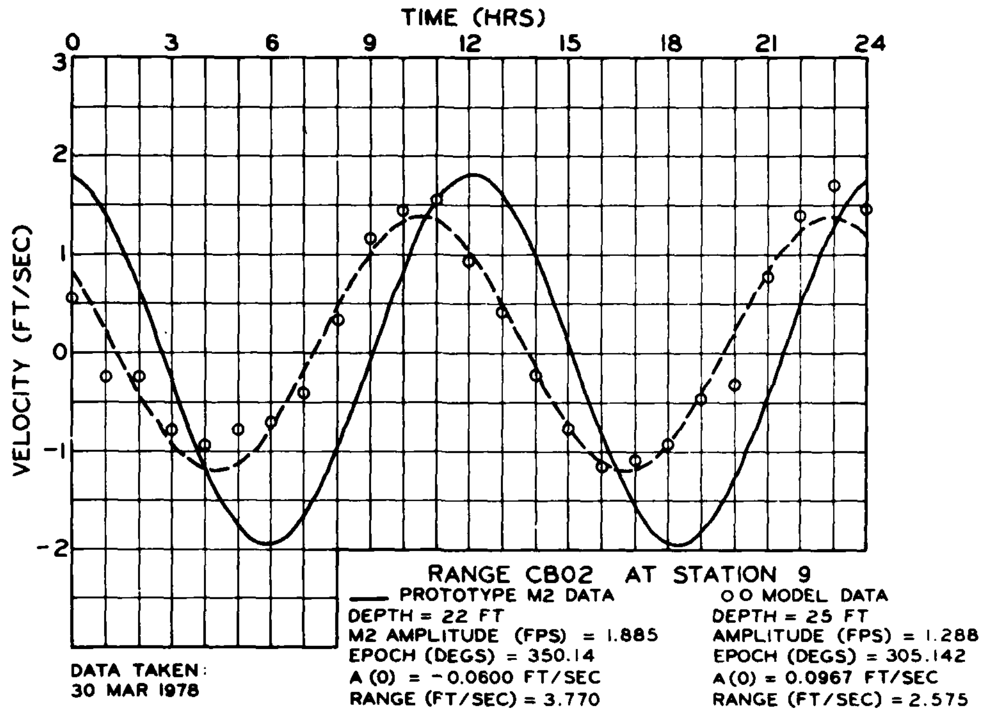




Plate C23. Model/prototype velocity comparison, Range CB02, sta 7 and 8



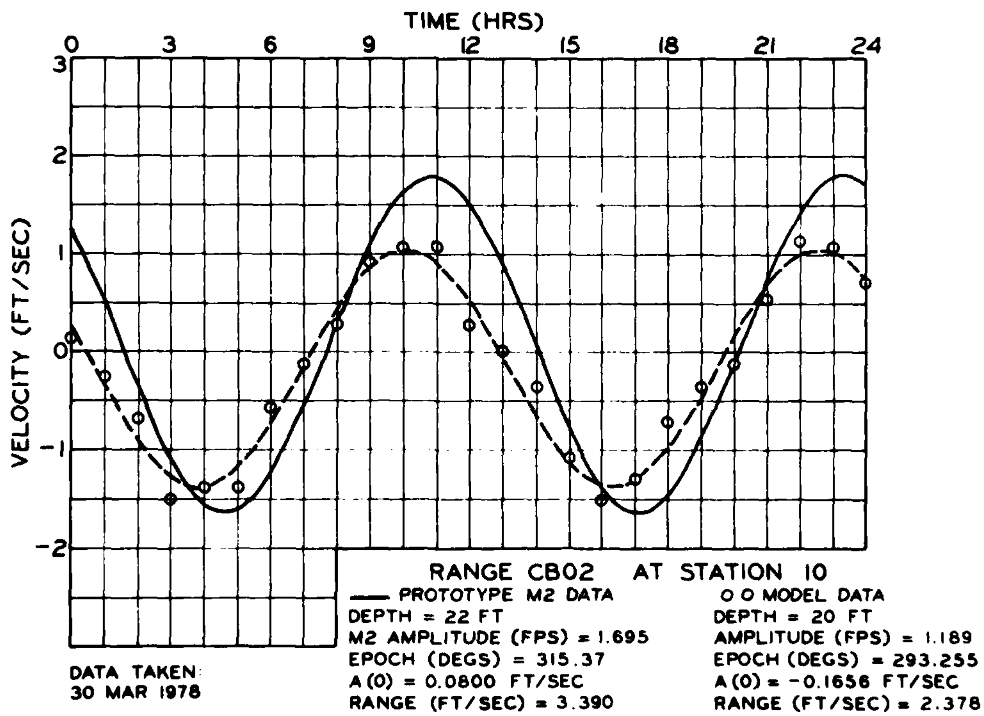
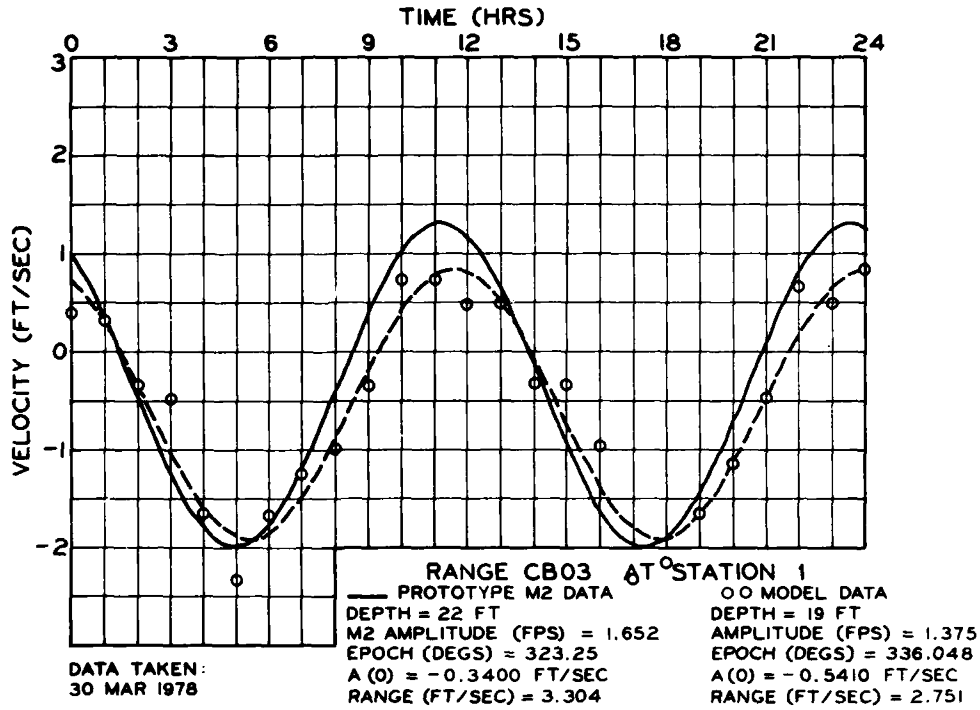




Plate C24. Model/prototype velocity comparison, Range CB02, sta 9 and 10



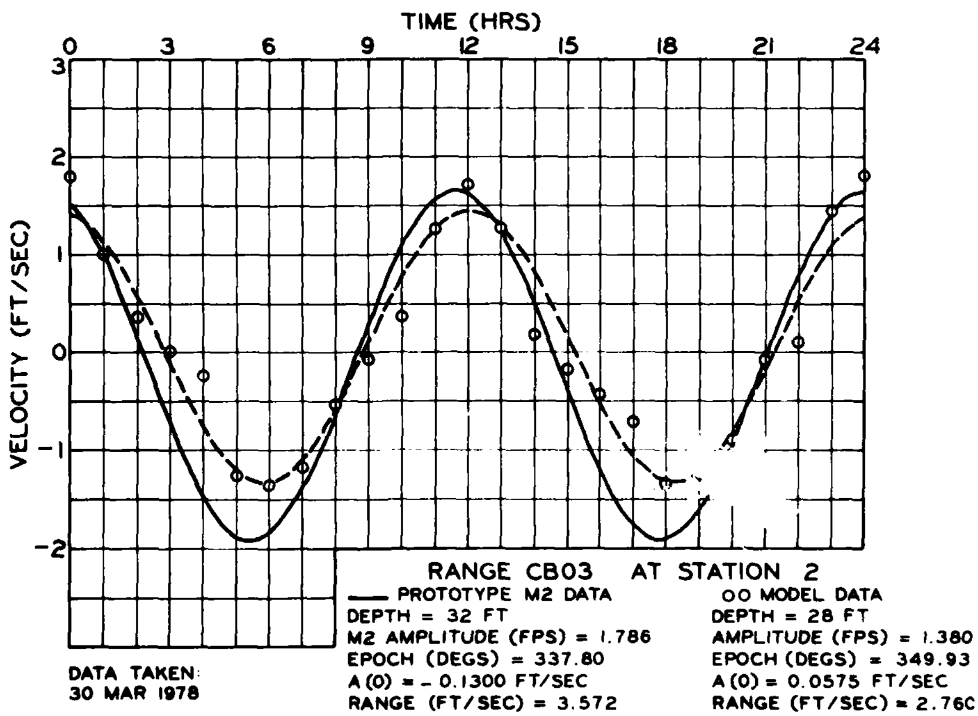
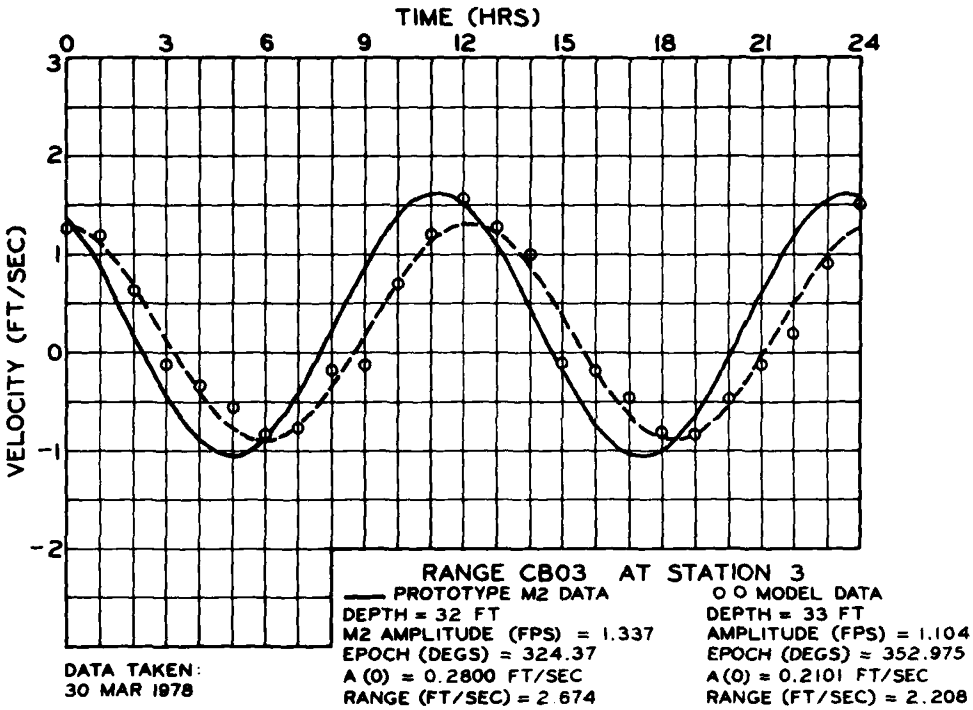




Plate C25. Model/prototype velocity comparison, Range CB03, sta 1 and 2



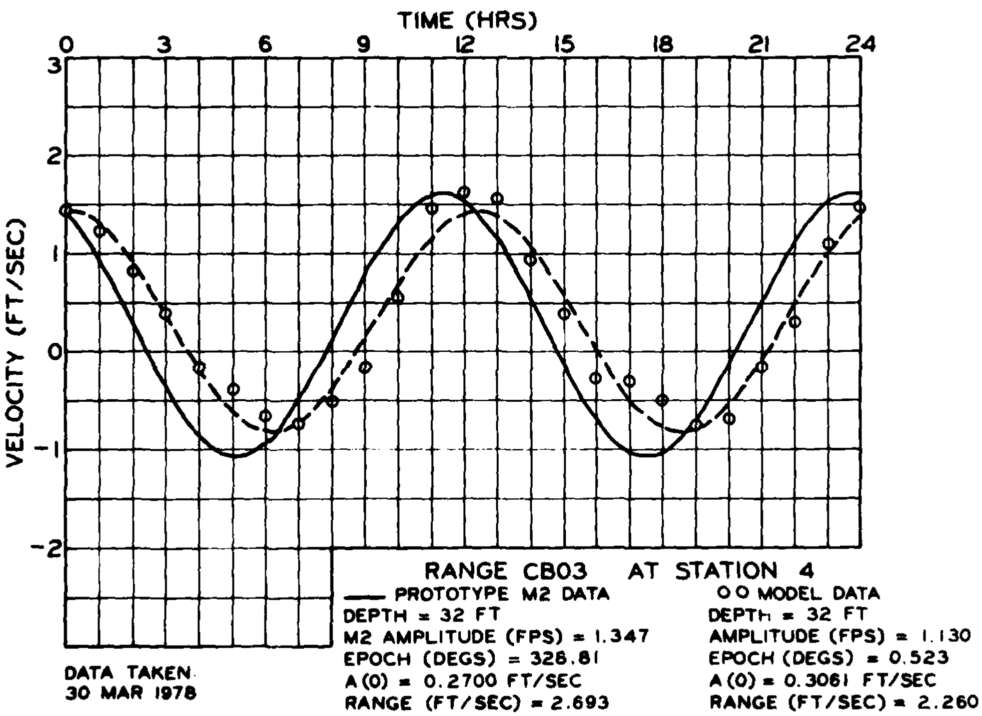
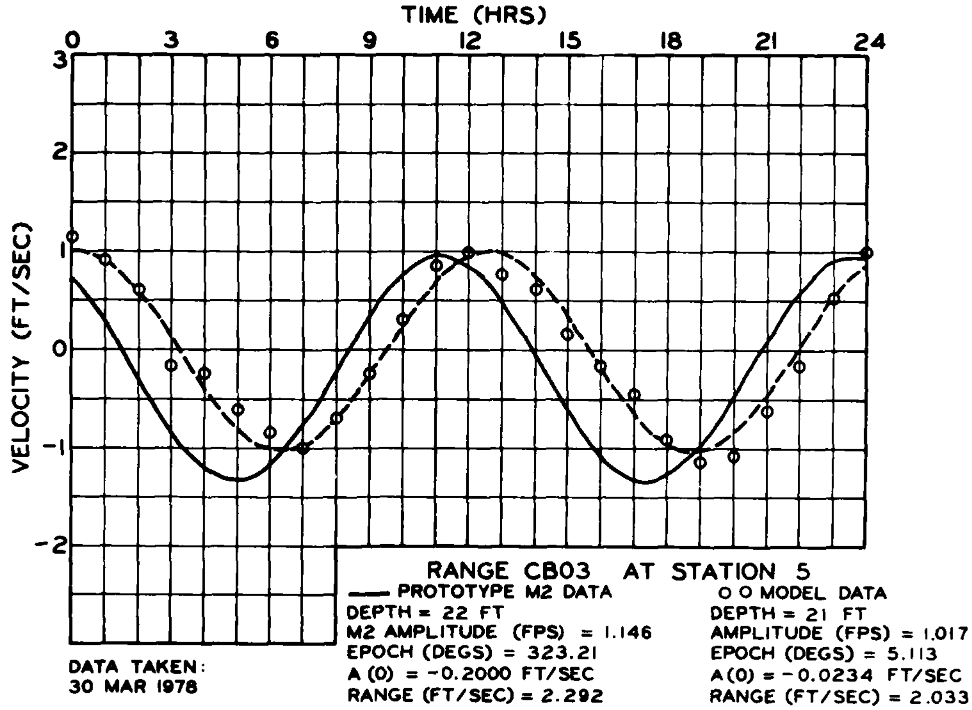




Plate C26. Model/prototype velocity comparison,
Range CB03, sta 3 and 4



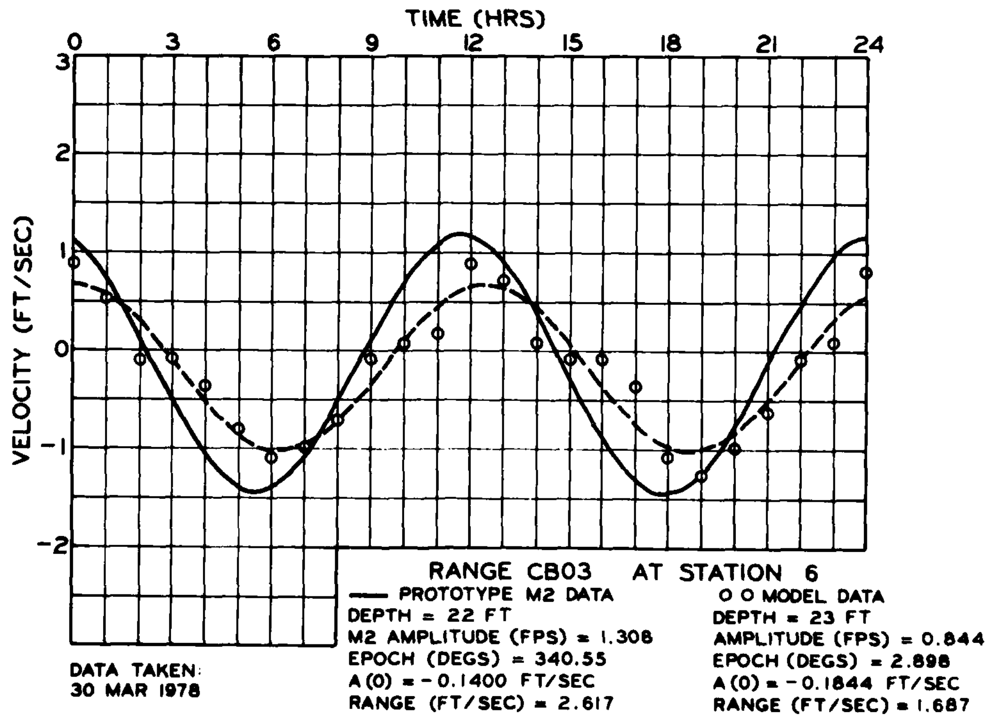
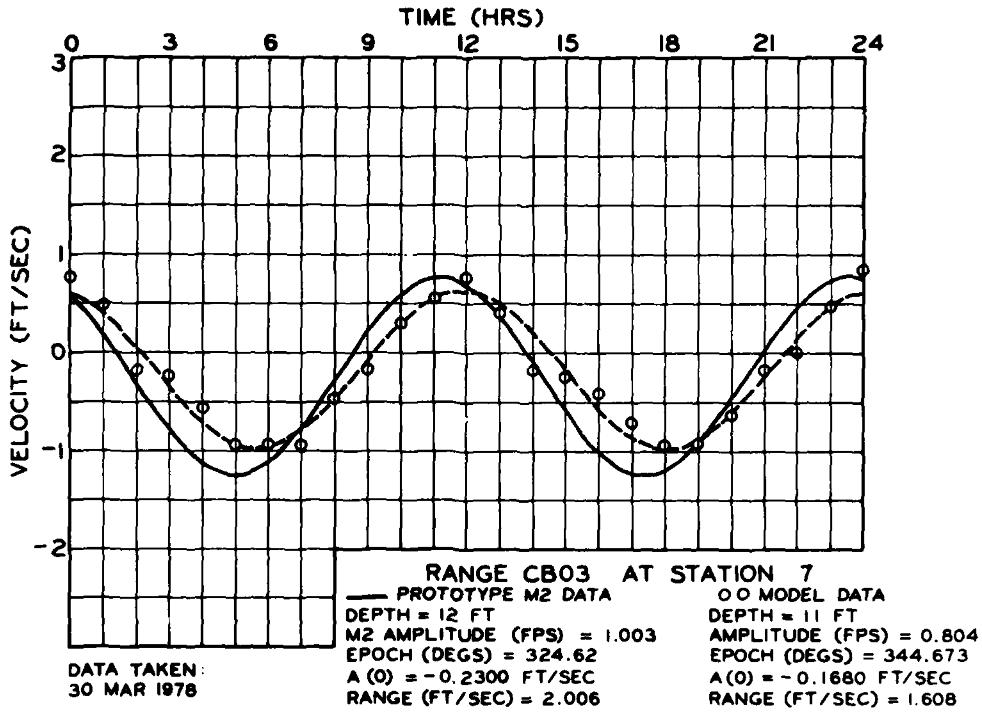




Plate C27. Model/prototype velocity comparison, Range CB03, sta 5 and 6



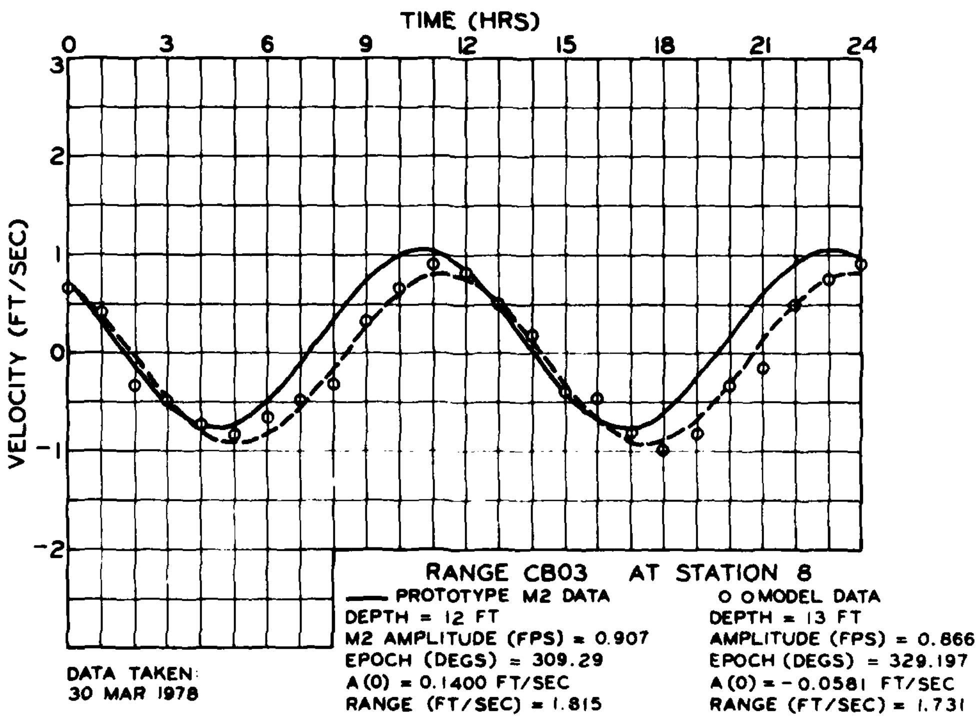
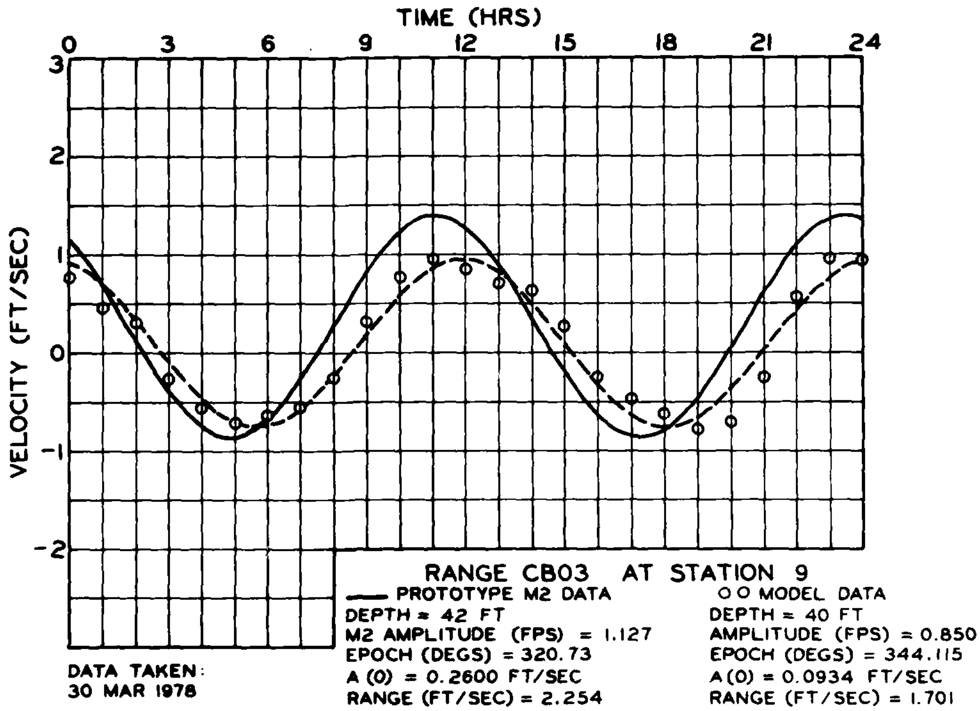




Plate C28. Model/prototype velocity comparison, Range CB03, sta 7 and 8



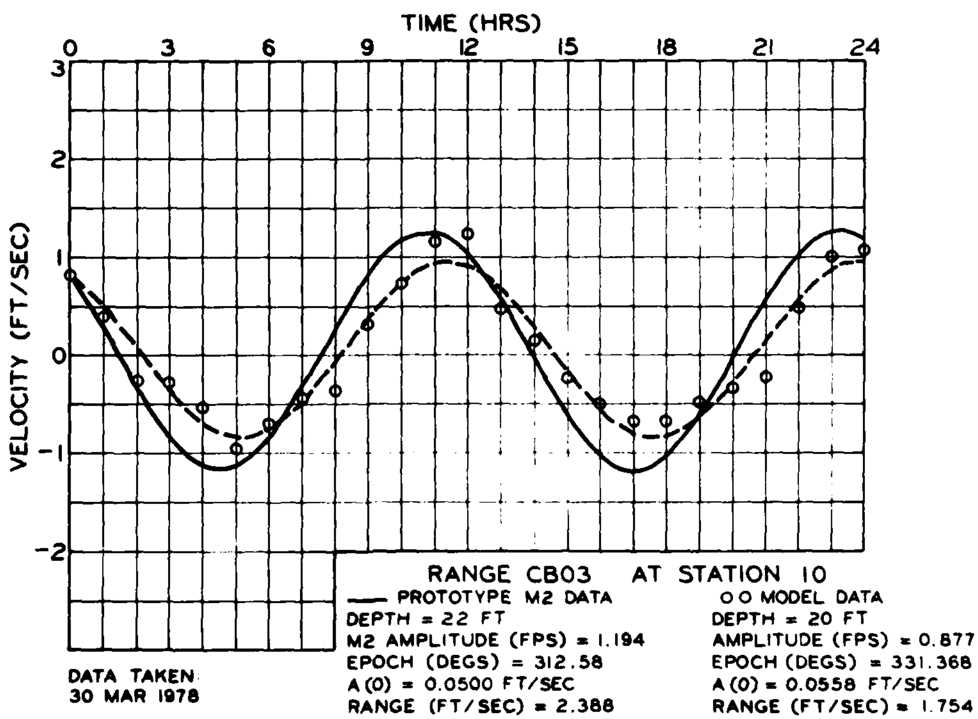
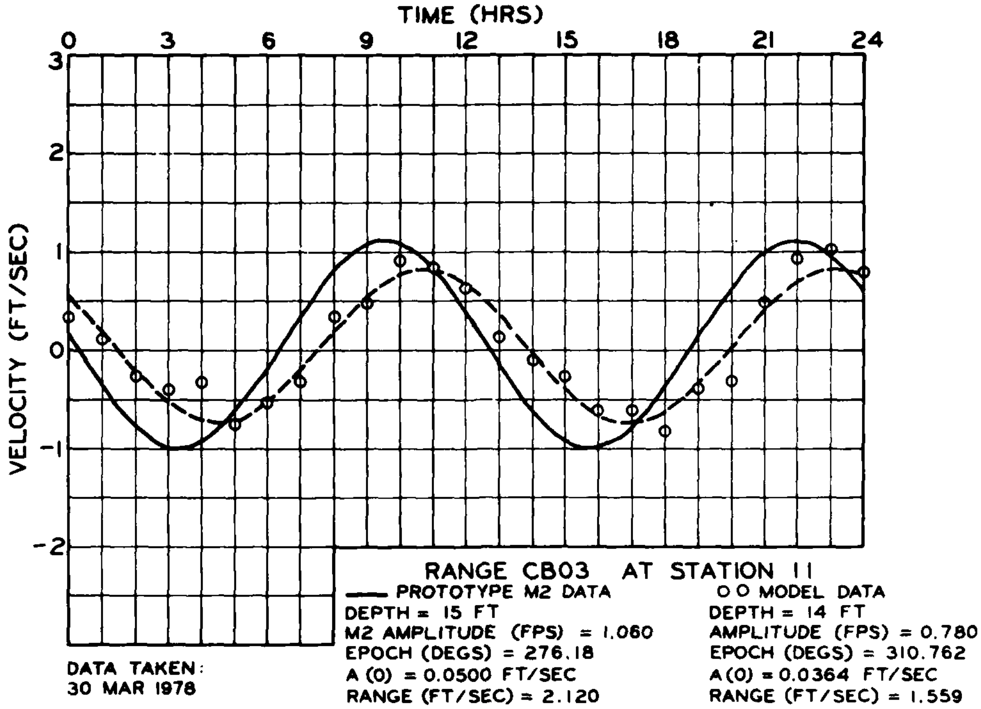




Plate C29. Model/prototype velocity comparison,
Range CB03, sta 9 and 10



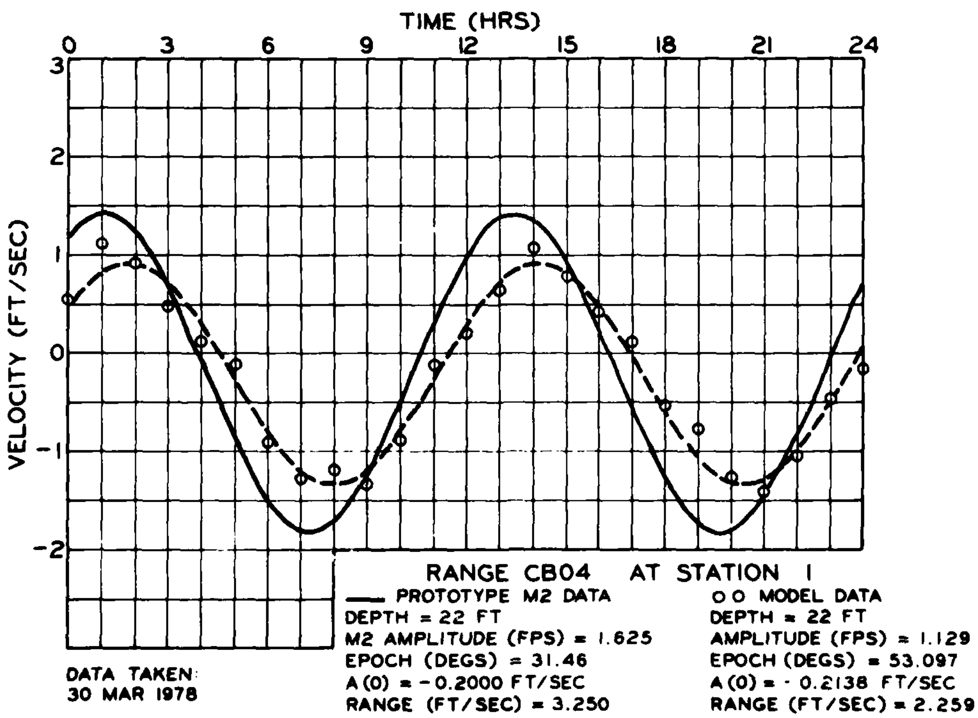
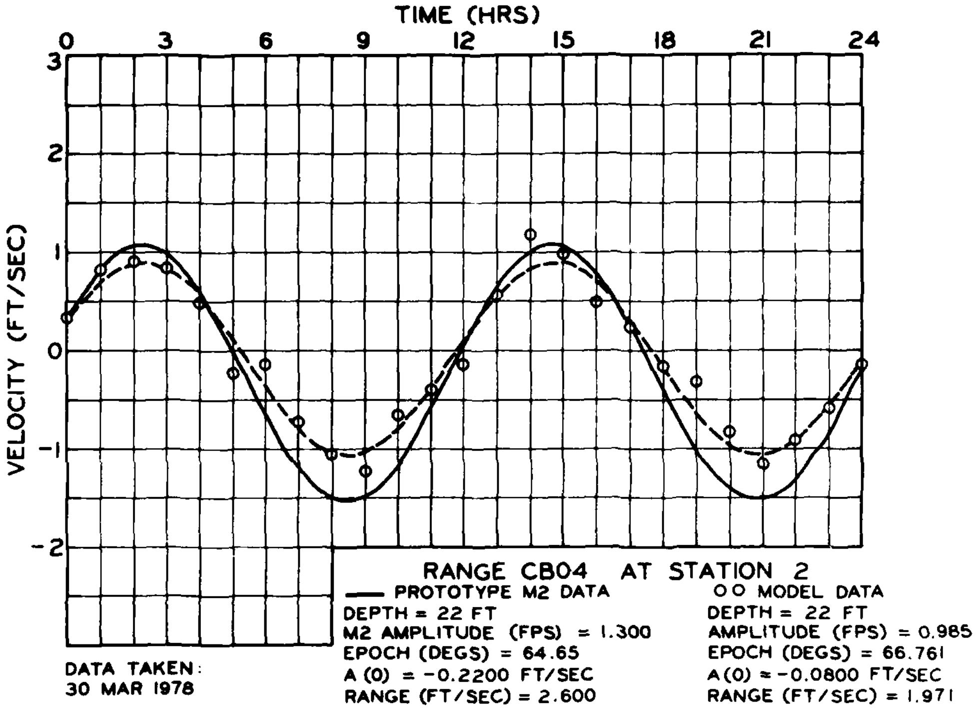




Plate C30. Model/prototype velocity comparison, Range CB03, sta 11 and Range CB04, sta 1



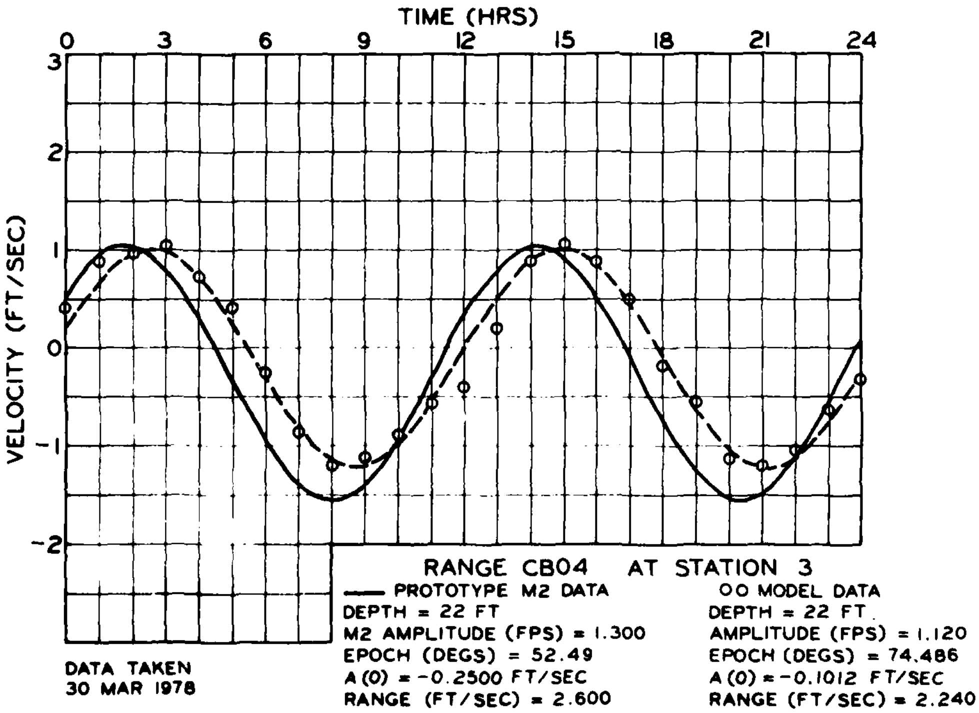
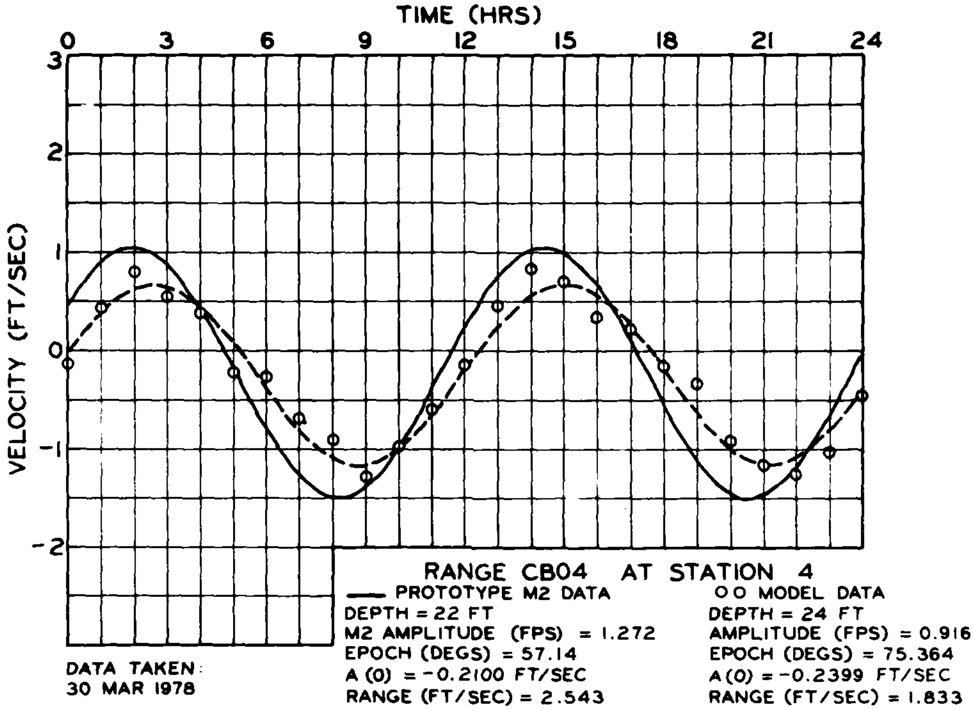




Plate C31. Model/prototype velocity comparison, Range CB04, sta 2 and 3



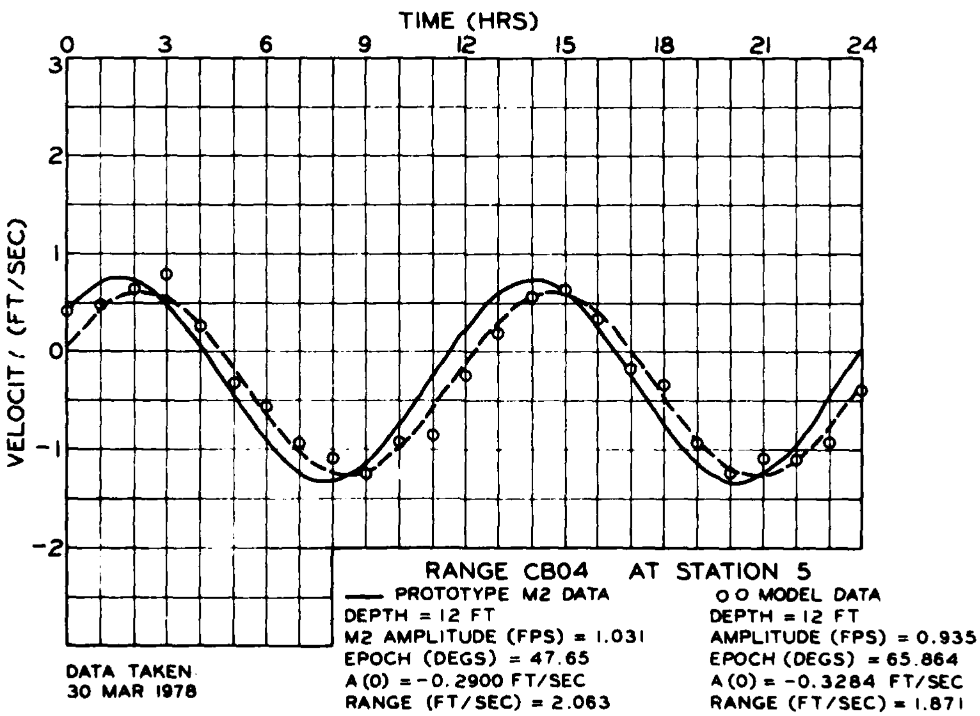
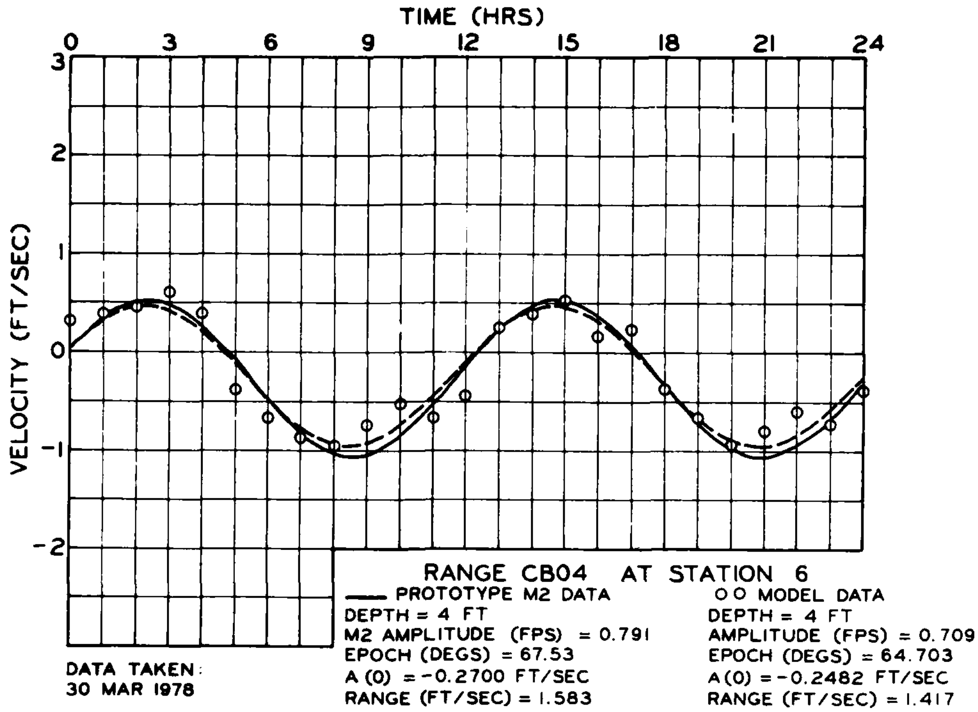




Plate C32. Model/prototype velocity comparison, Range CB04, sta 4 and 5



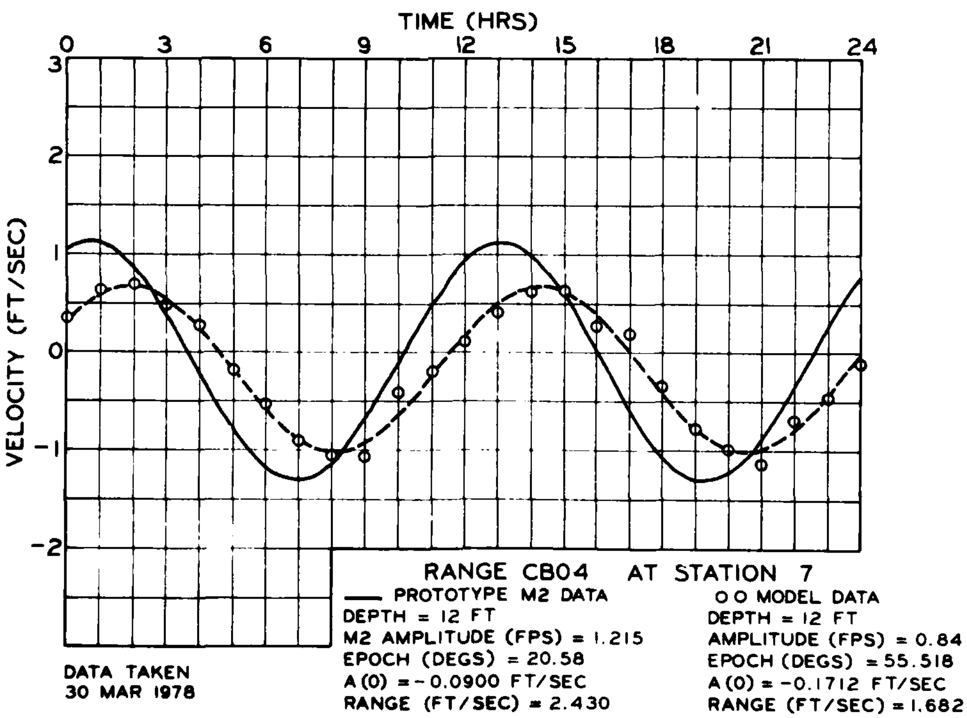
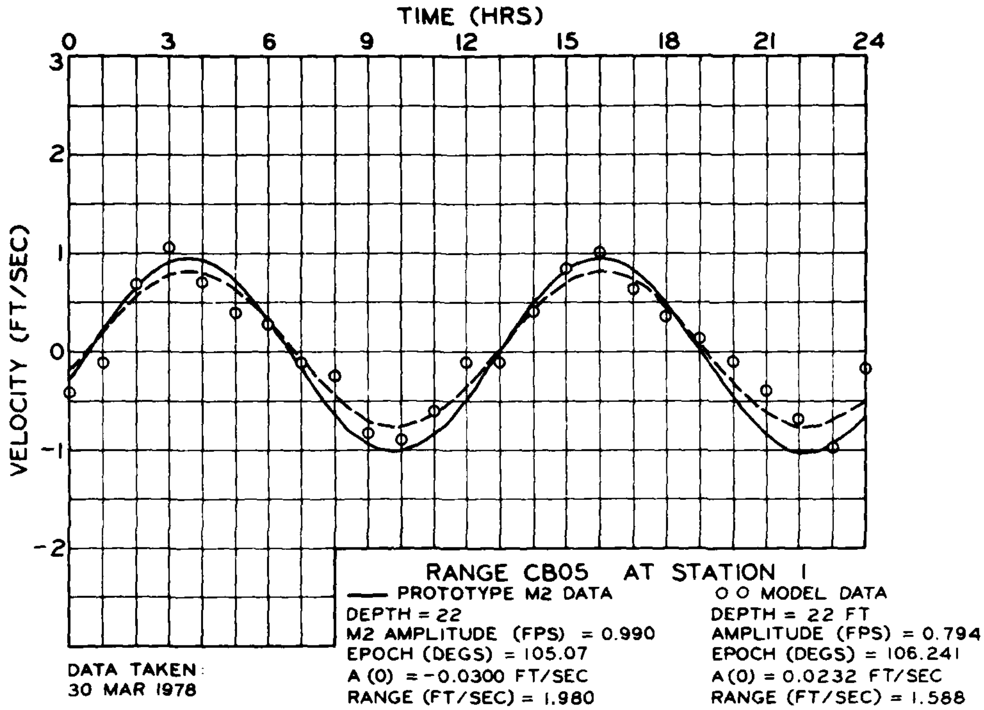




Plate C33. Model/prototype velocity comparison, Range CBC4, sta 6 and 7



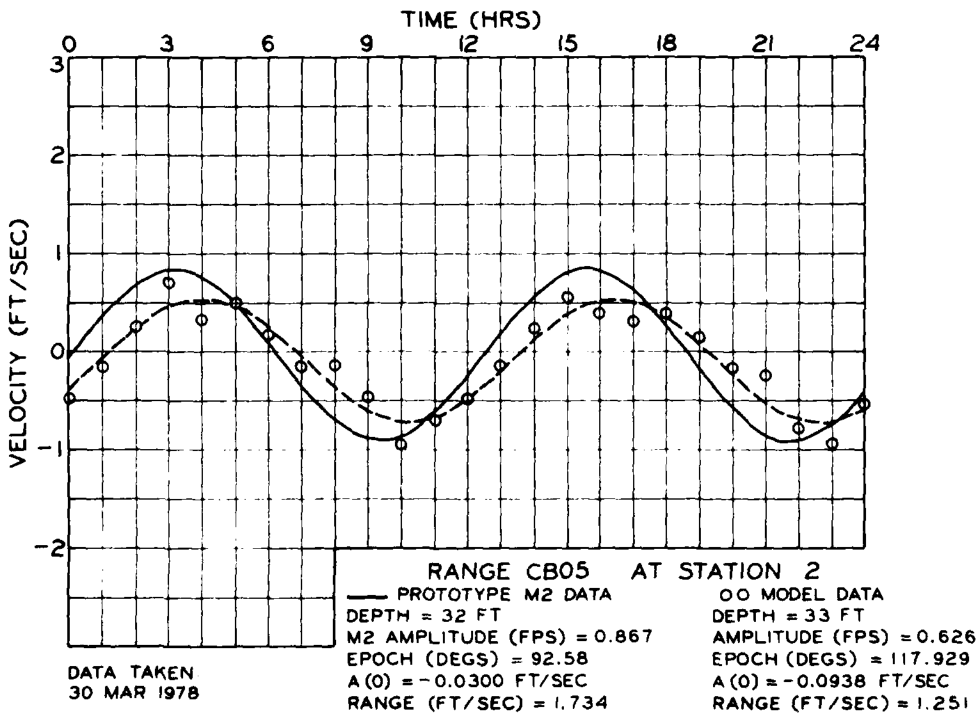
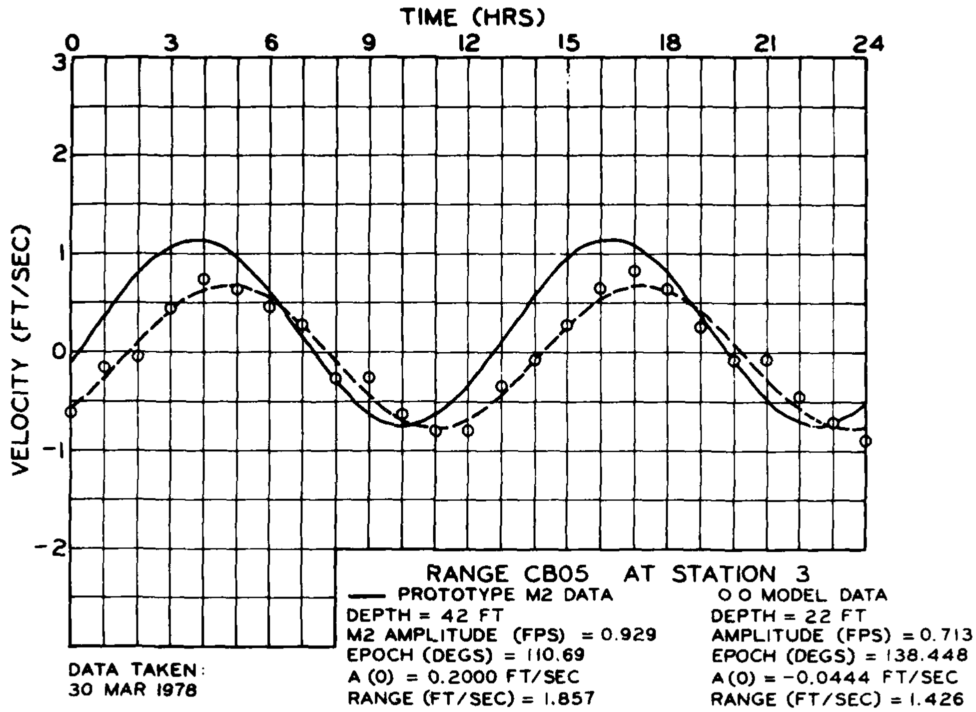




Plate C34. Model/prototype velocity comparison,
Range CB05, sta 1 and 2



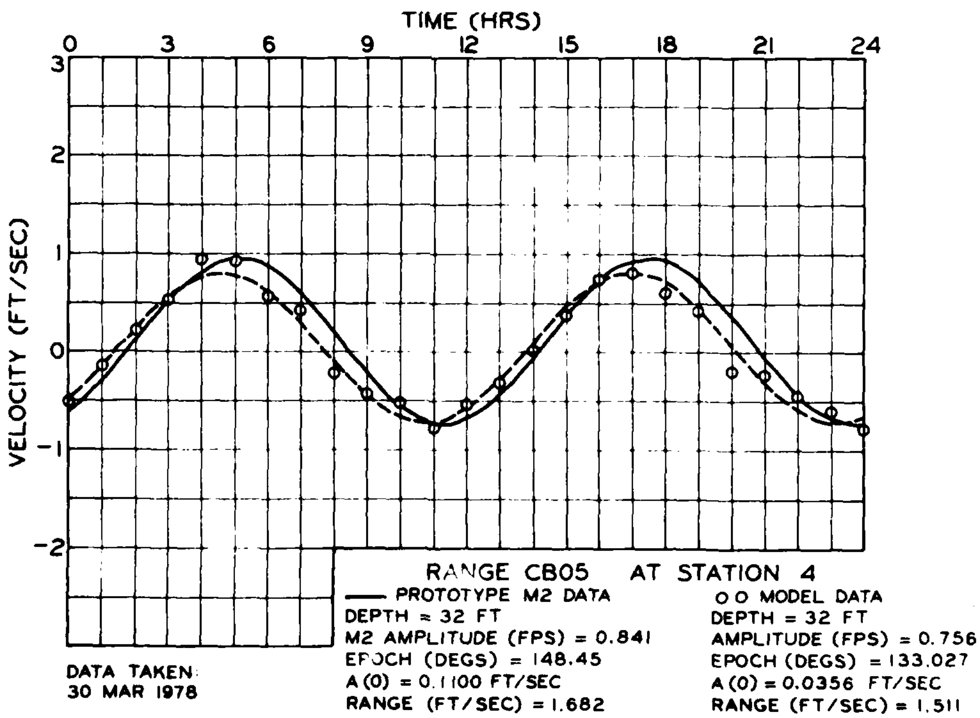
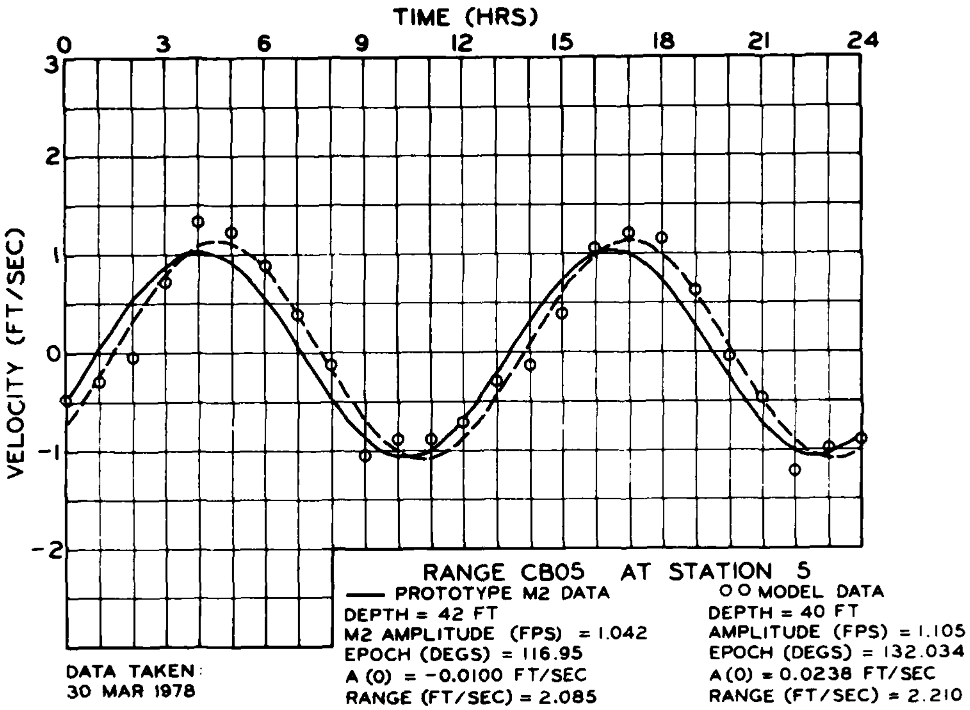




Plate C35. Model/prototype velocity comparison, Range C305, sta 3 and 4



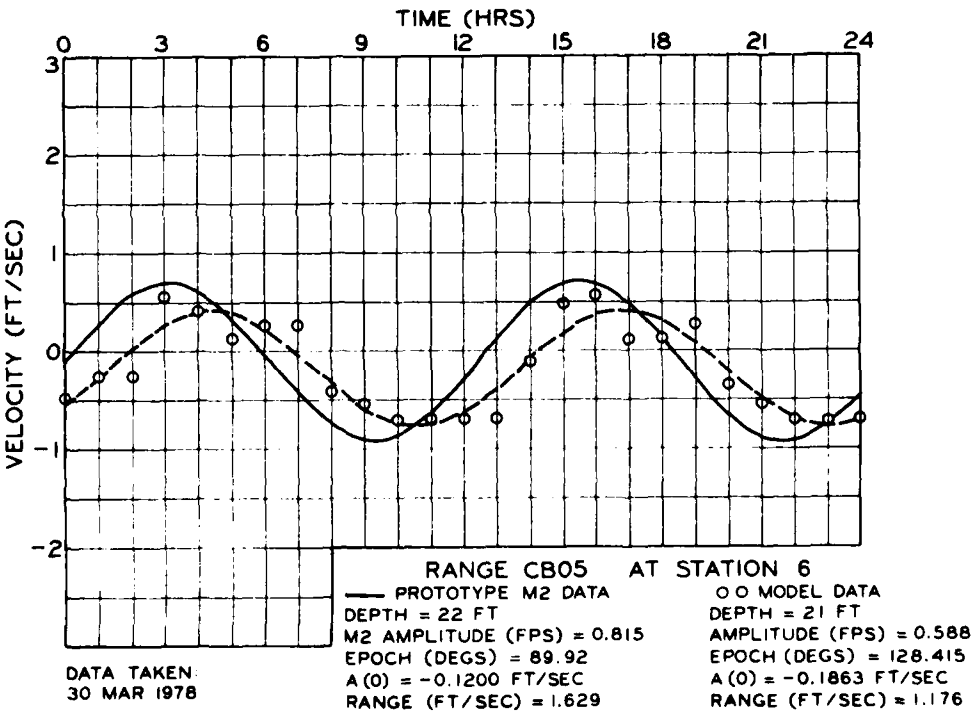
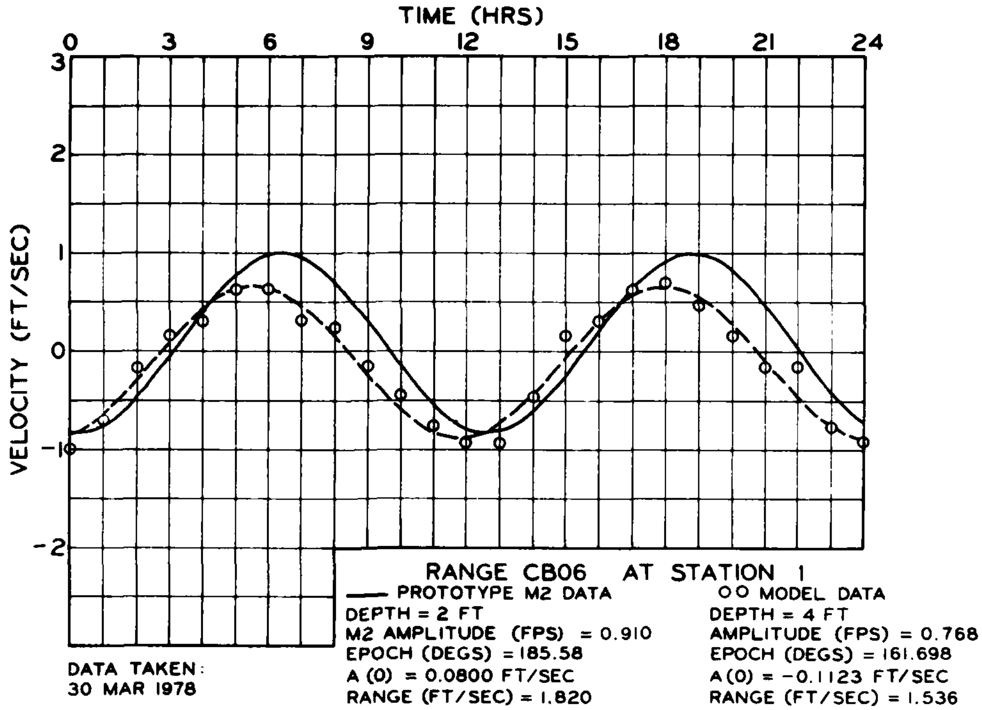




Plate C36. Model/prototype velocity comparison,
Range CB05, sta 5 and 6



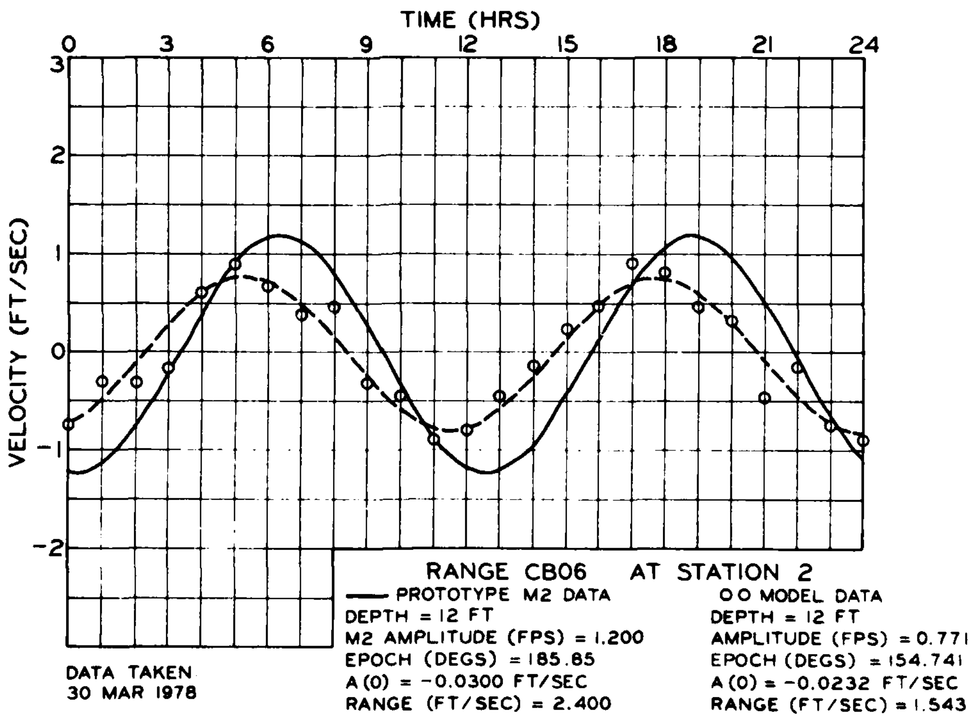
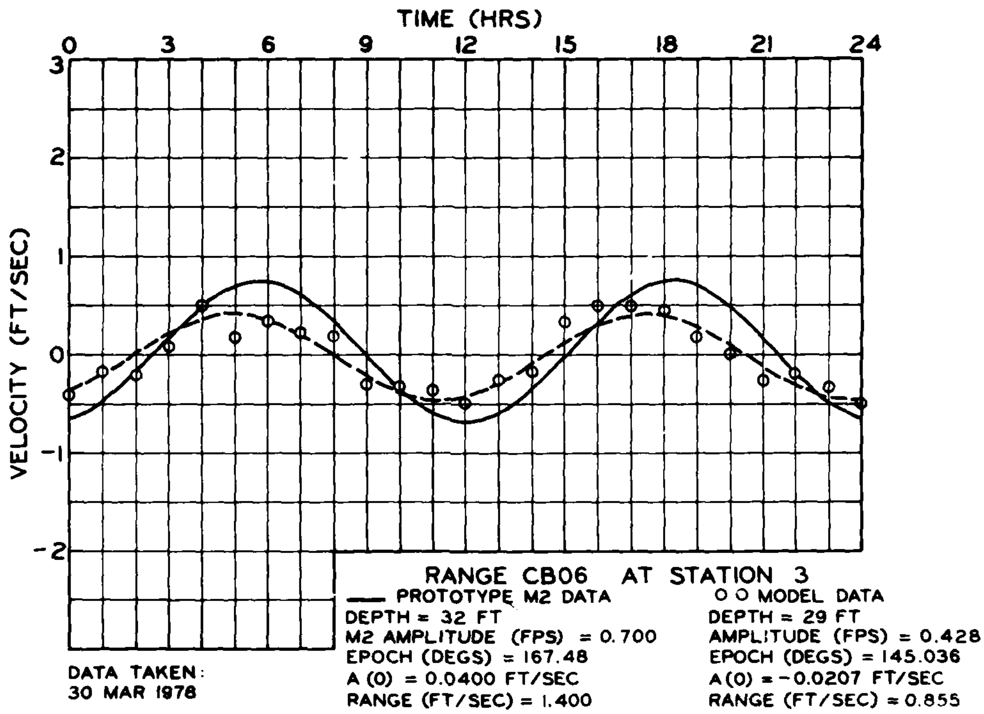




Plate C37. Model/prototype velocity comparison, Range CB06, sta 1 and 2



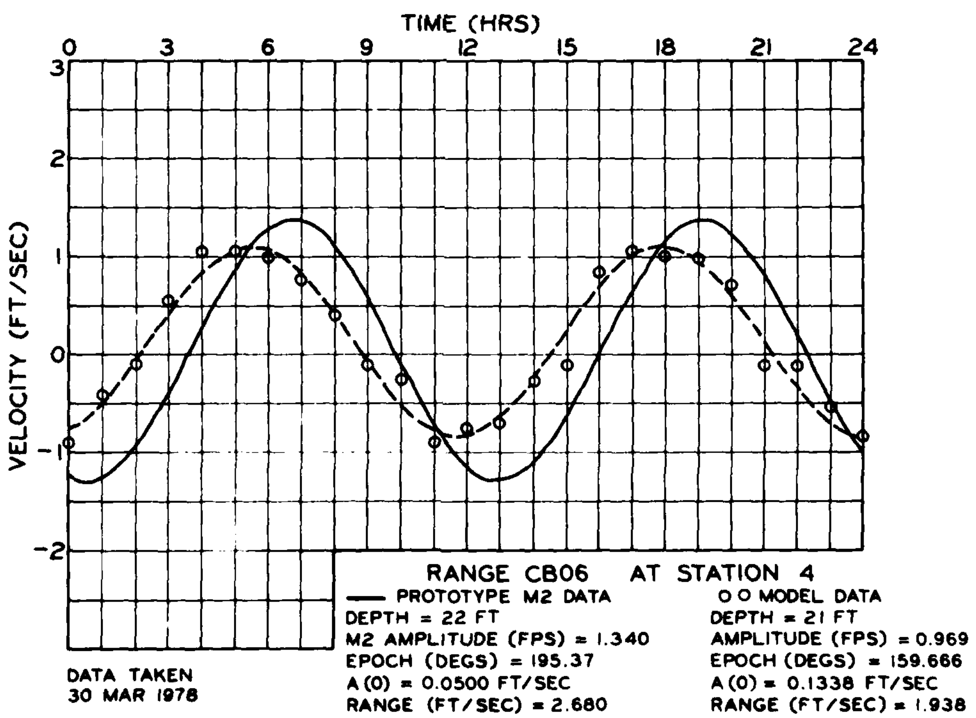
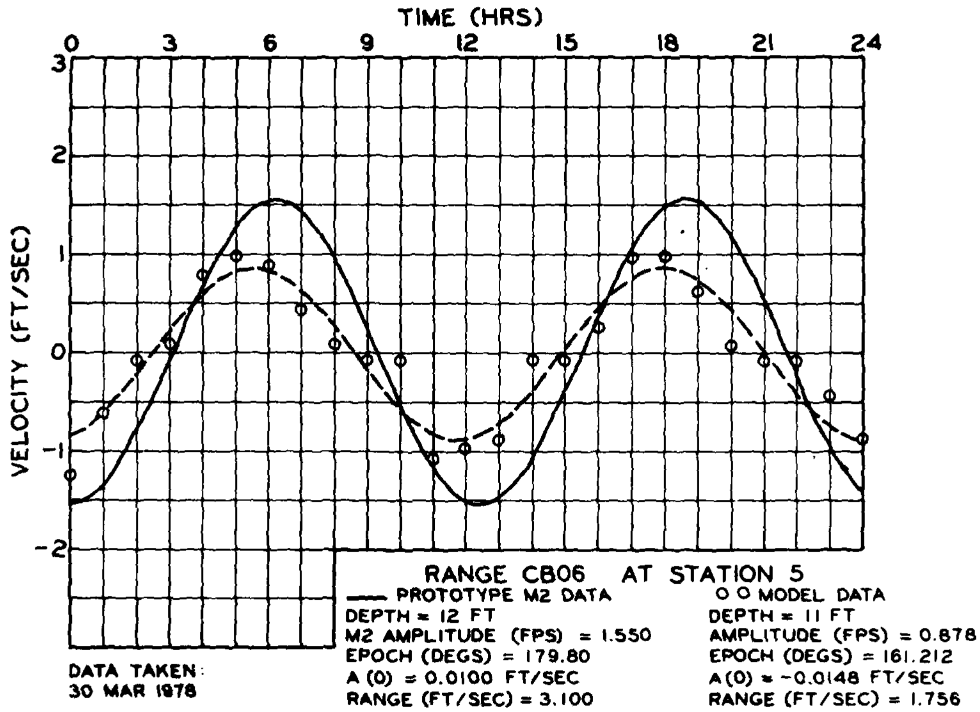




Plate C38. Model/prototype velocity comparison, Range CB06, sta 3 and 4



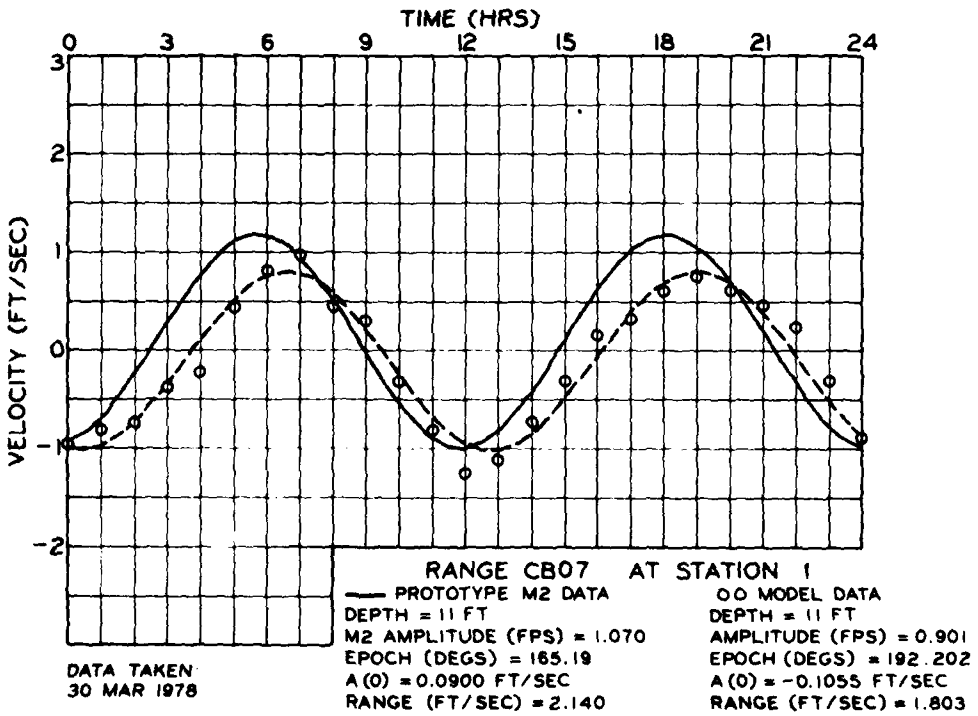
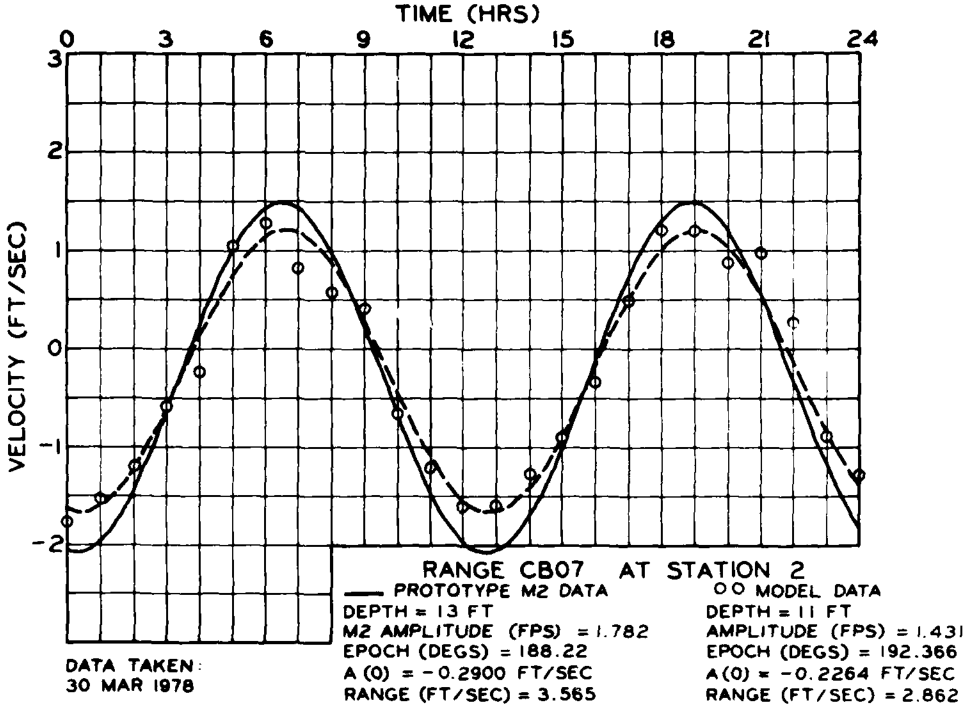




Plate C39. Model/prototype velocity comparison, Range CB06, sta 5 and Range CB07, sta 1



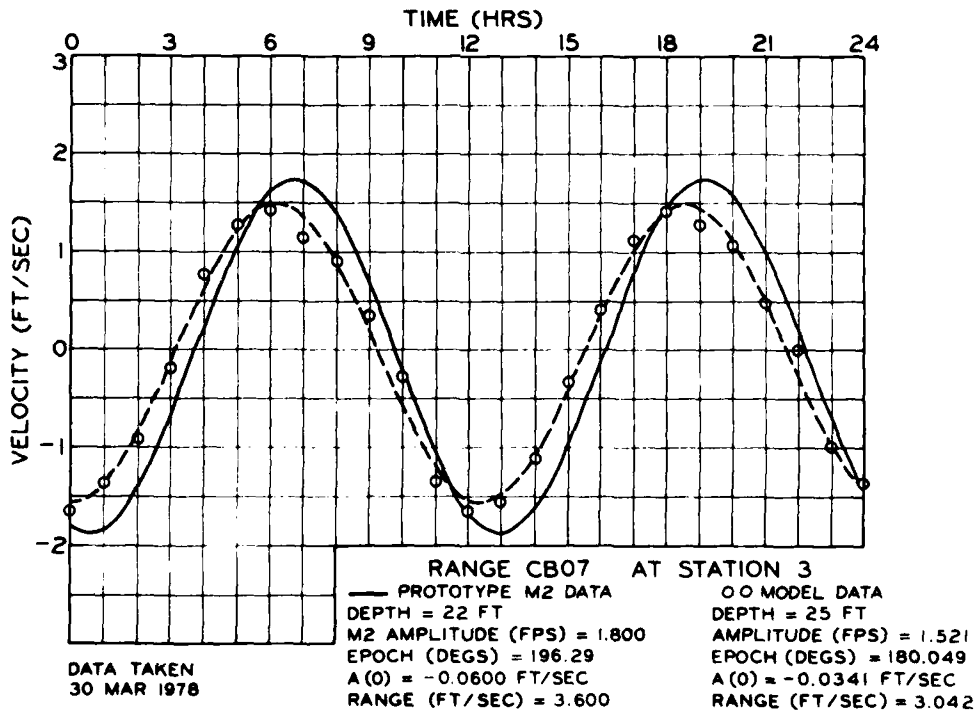
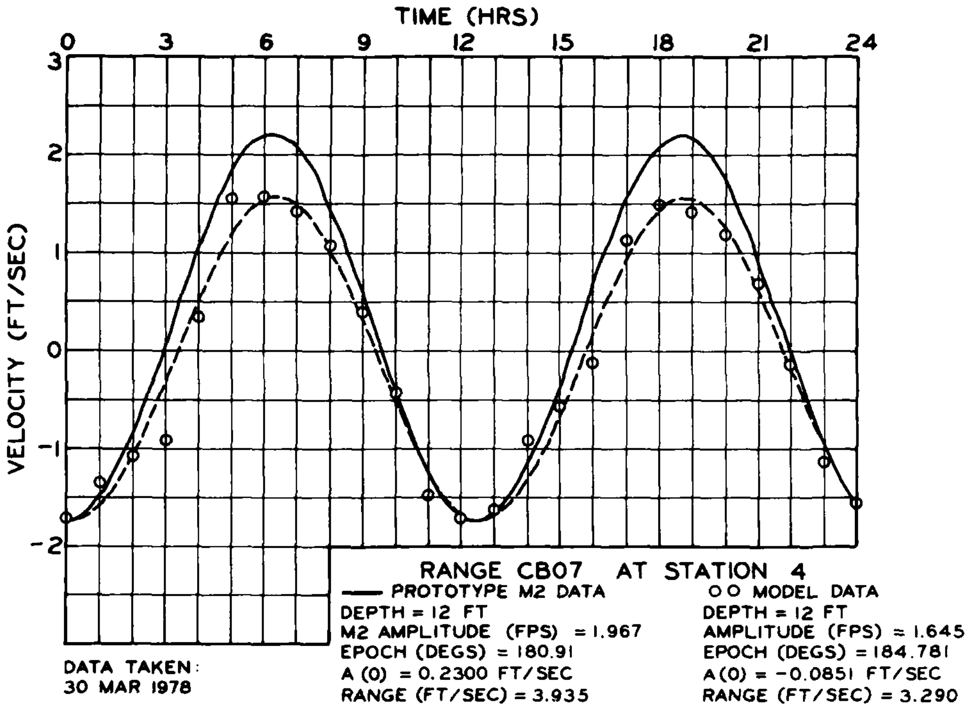




Plate C40. Model/prototype velocity comparison, Range CB07, sta 2 and 3



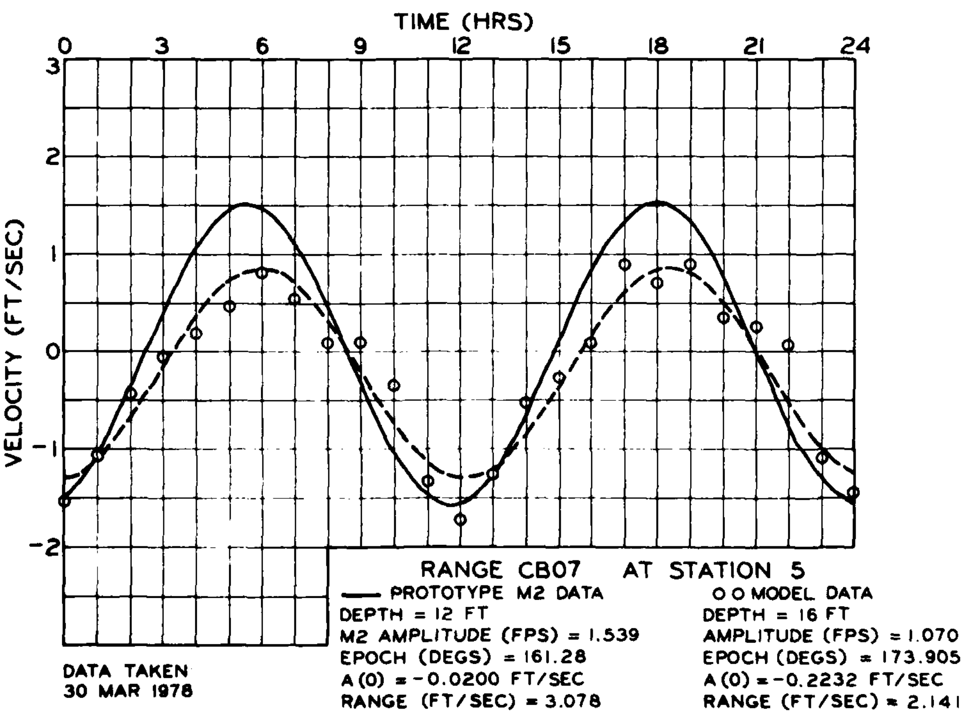
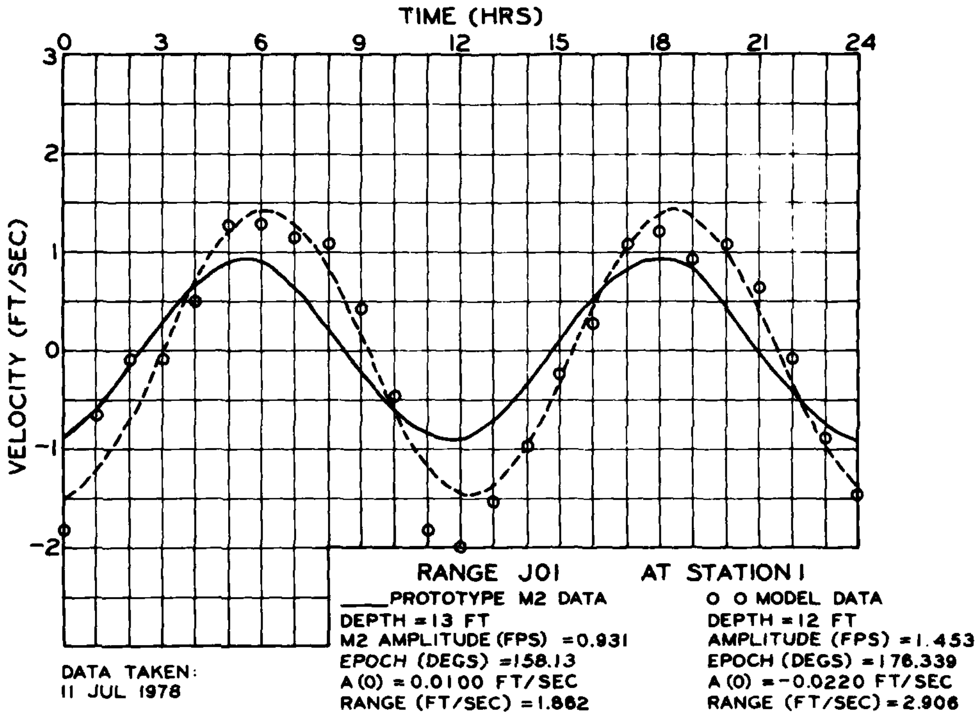




Plate C41. Model/prototype velocity comparison,
Range CB07, sta 4 and 5



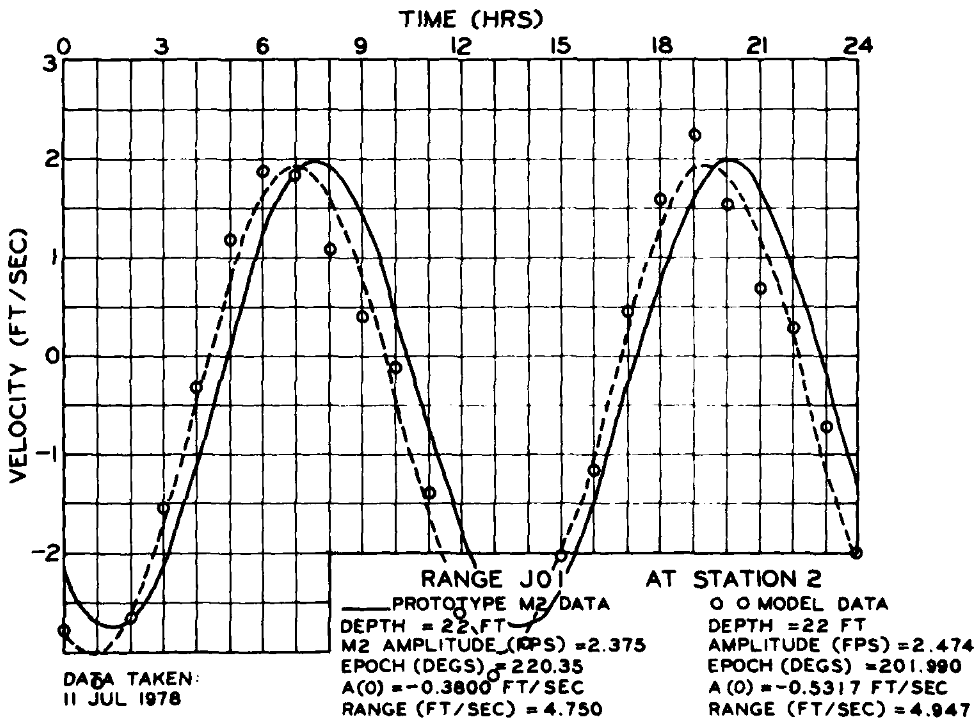
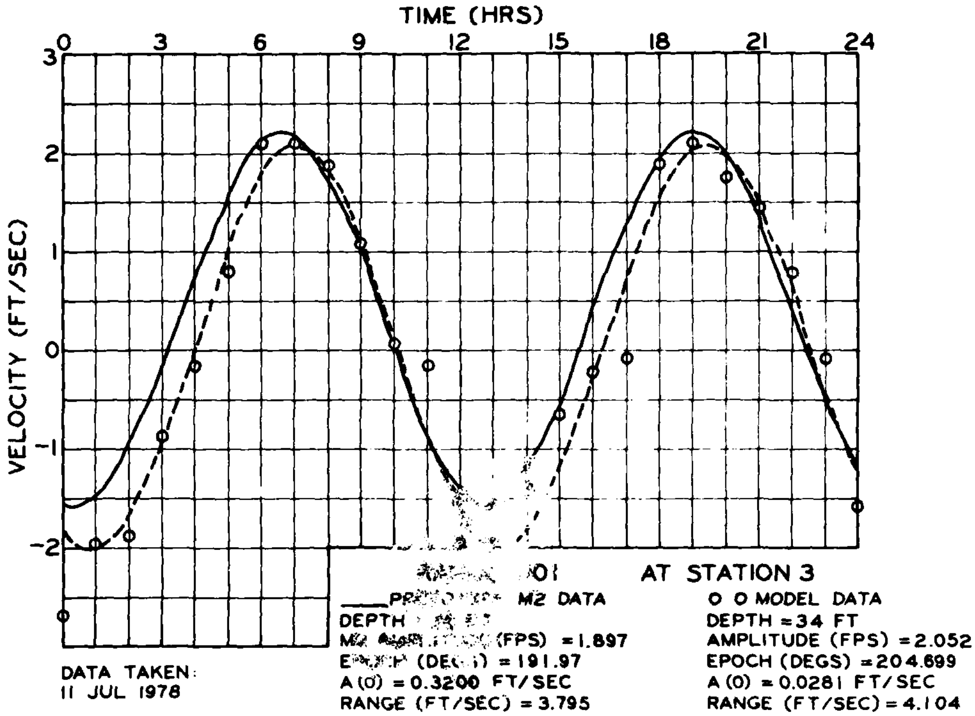




Plate C42. Model/prototype velocity comparison, Range J01, sta 1 and 2



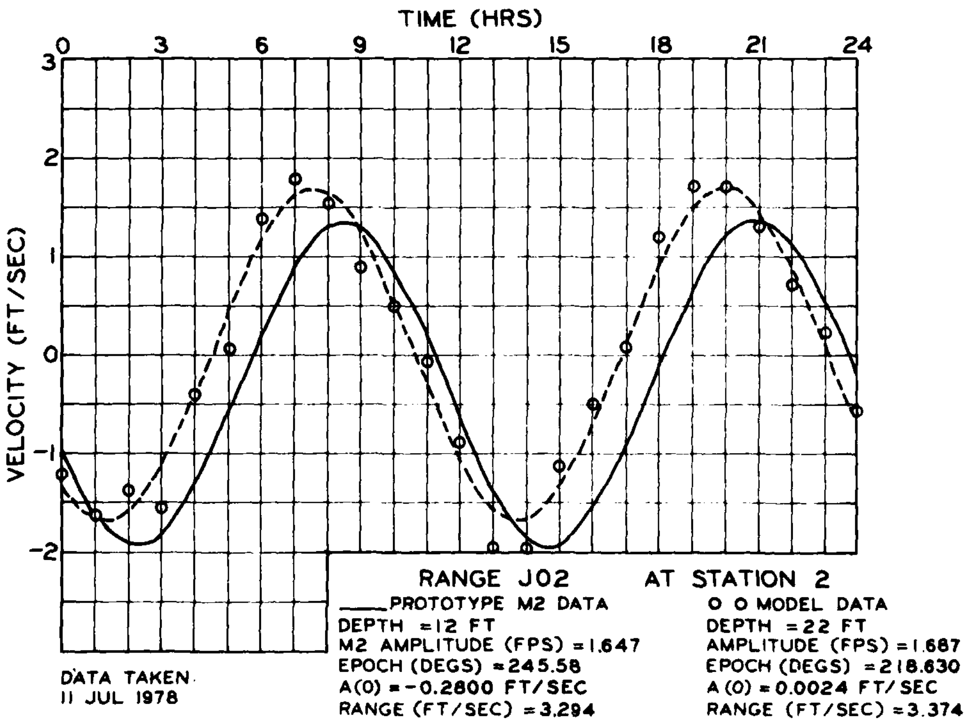
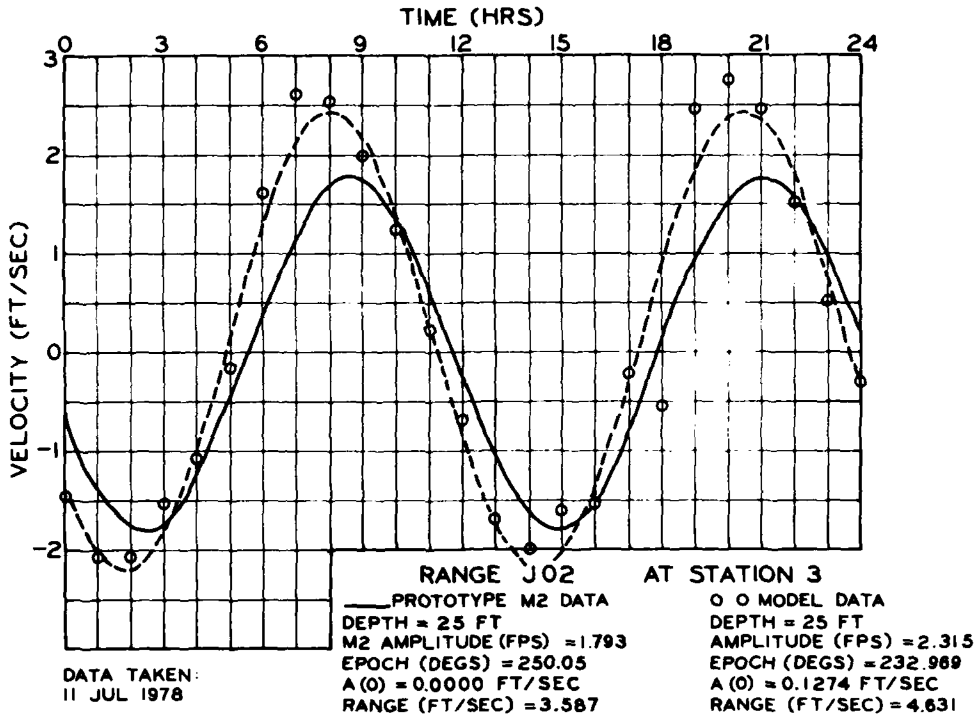




Plate C43. Model/prototype velocity comparison, Range J01, sta 3 and Range J02, sta 2



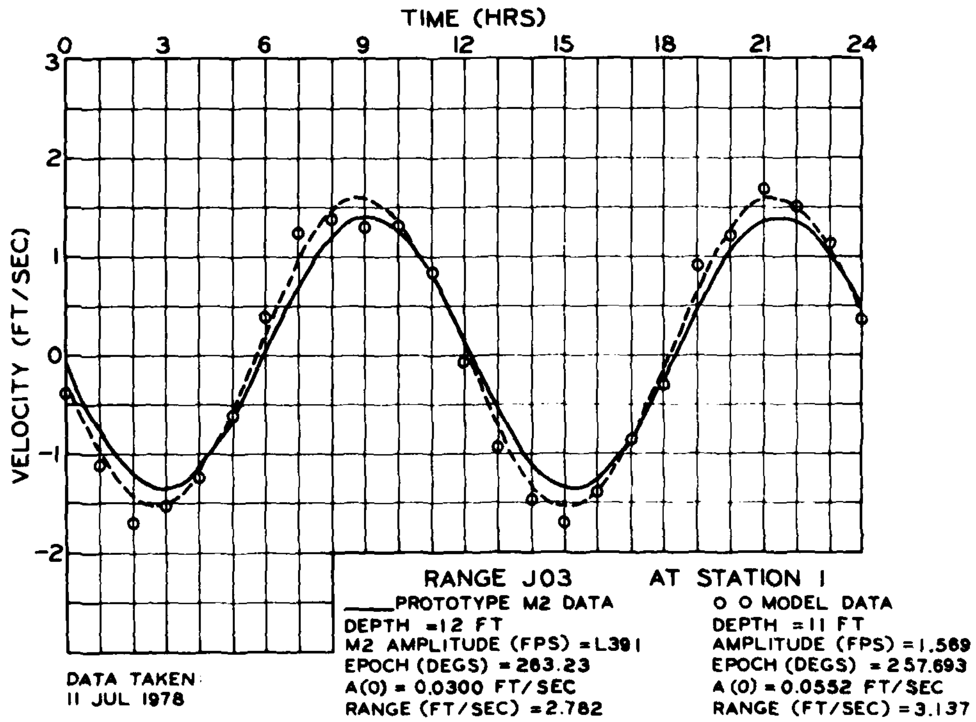
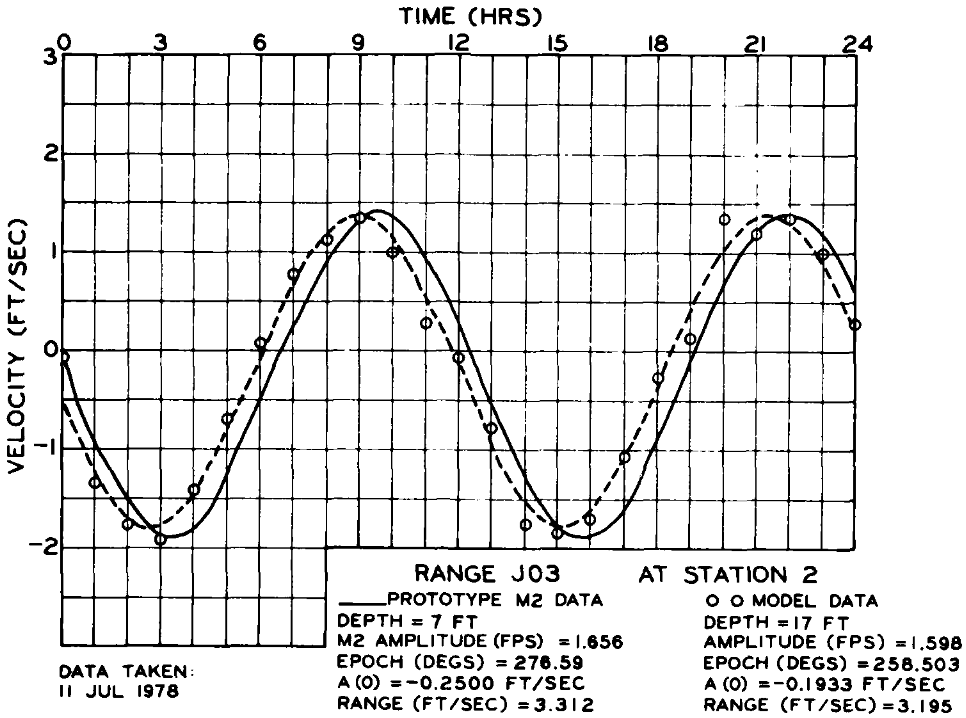




Plate C44. Model/prototype velocity comparison, Range J02, sta 3 and Range J03, sta 1



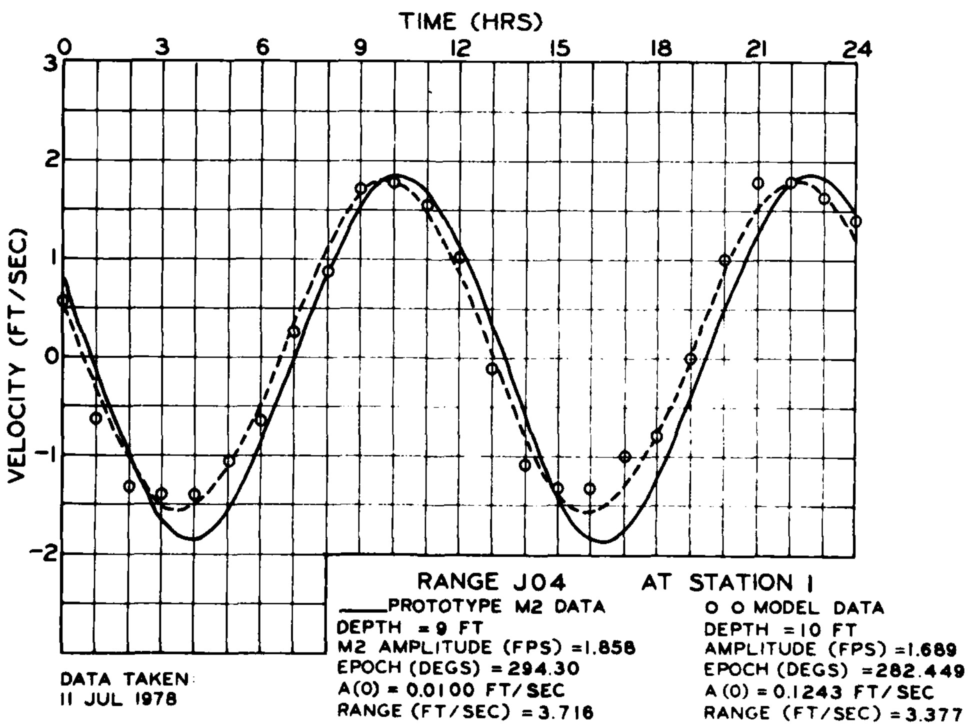
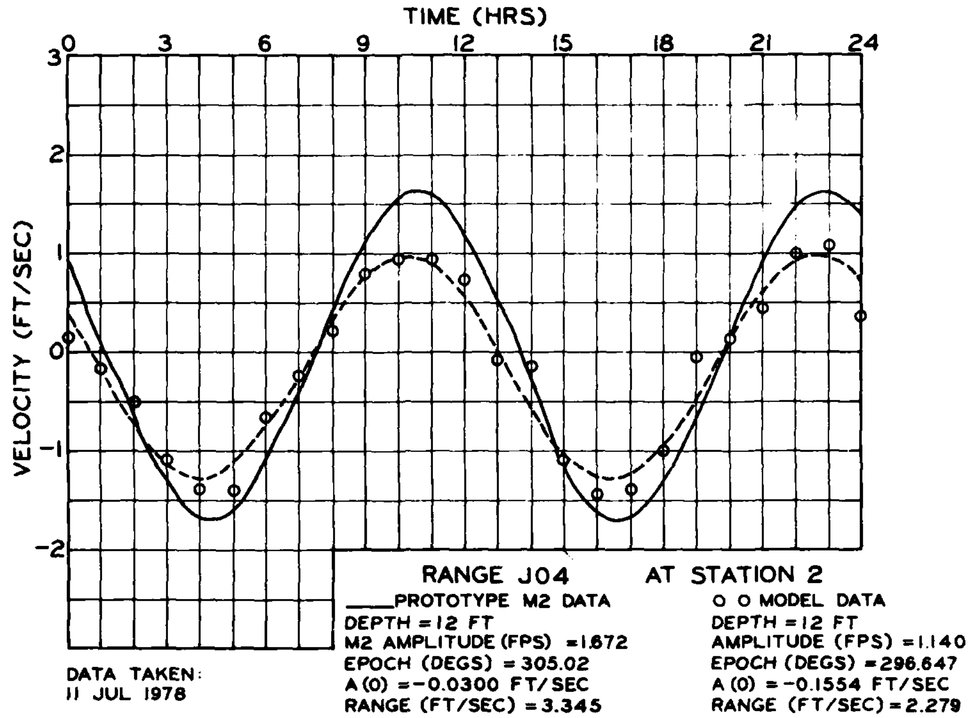




Plate C45. Model/prototype velocity comparison, Range J03, Sta 2 and Range J04, sta 1



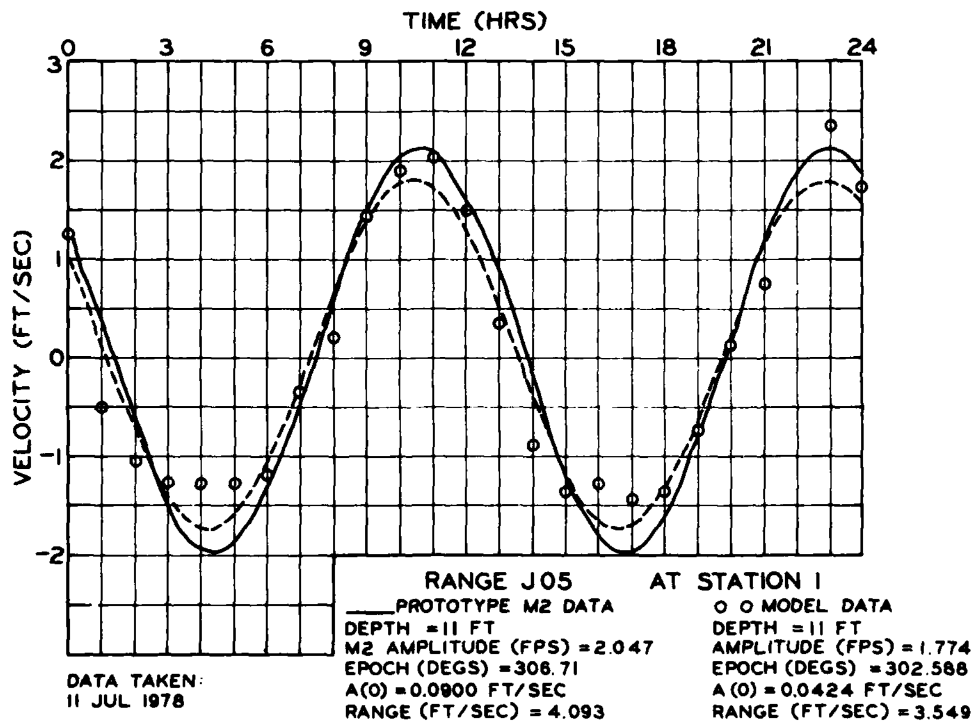
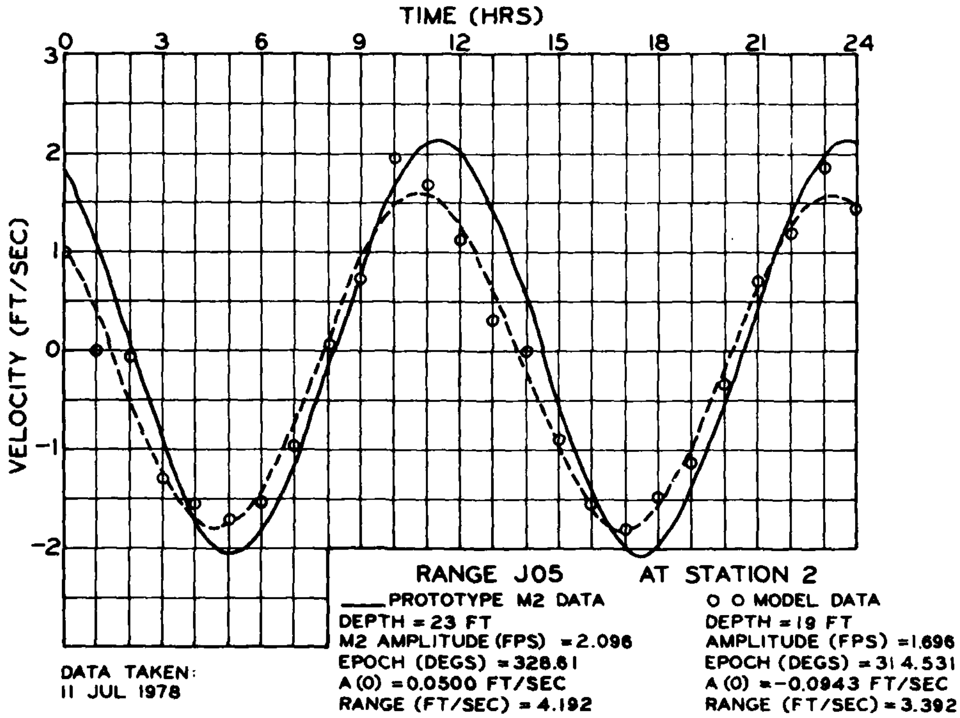




Plate C46. Model/prototype velocity comparison,
Range J04, sta 2 and Range J05, sta 1



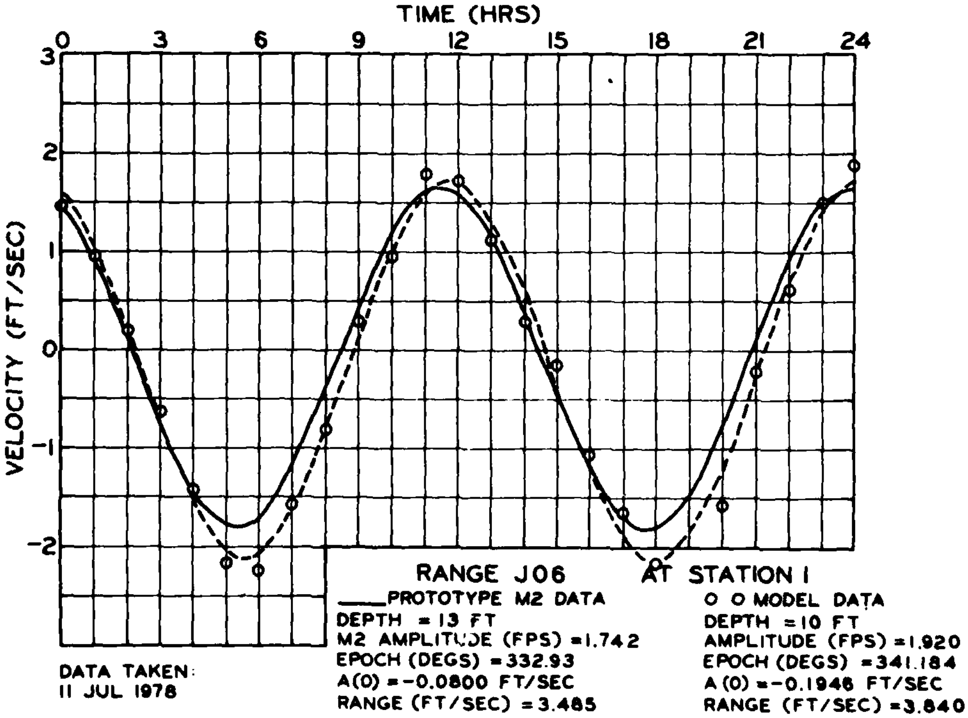
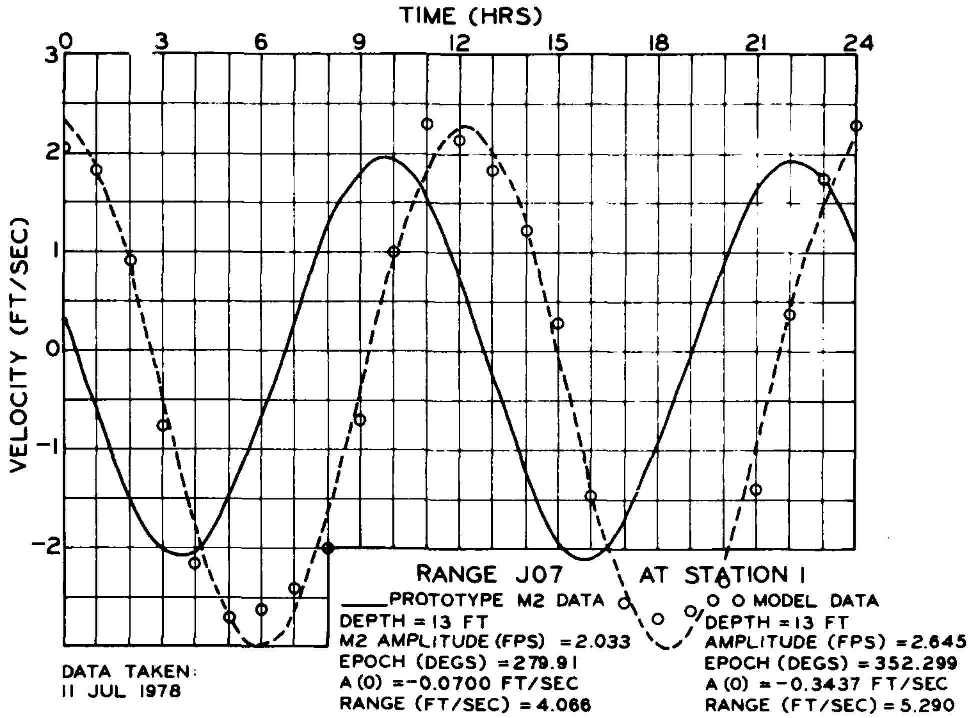




Plate C47. Model/prototype velocity comparison, Range J05, sta 2 and Range J06, sta 1



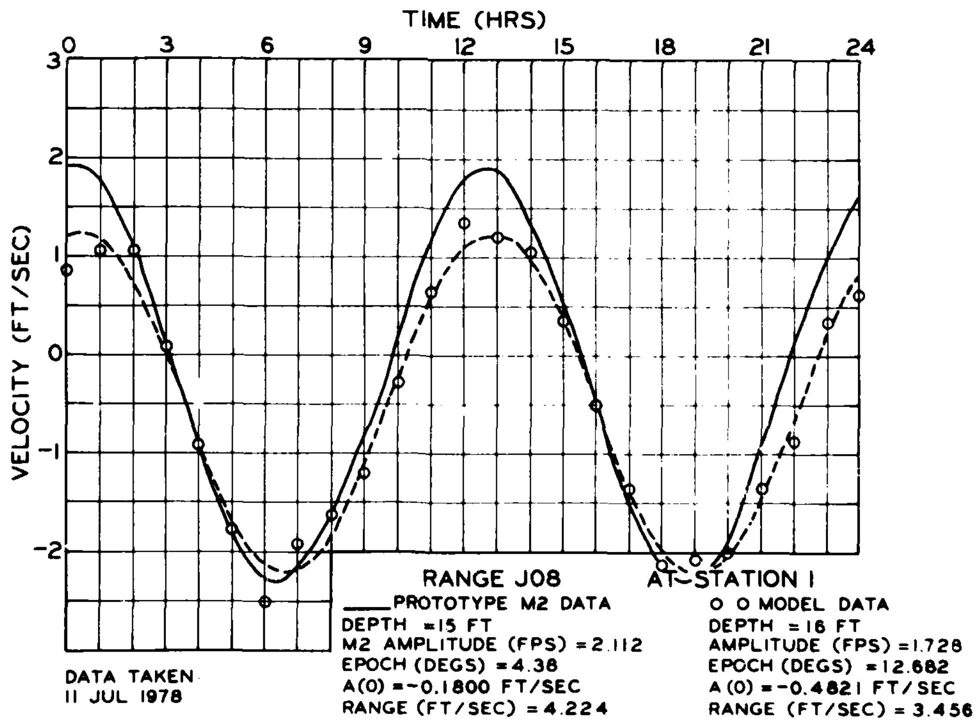
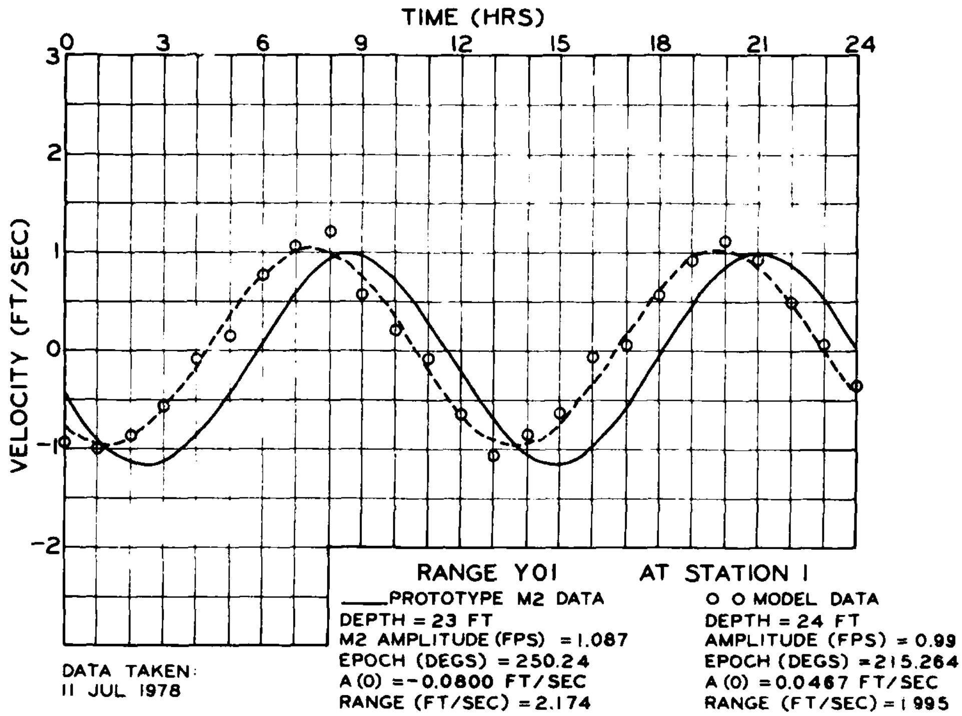




Plate C48. Model/prototype velocity comparison,
Range J07, sta 1 and Range J08, sta 1



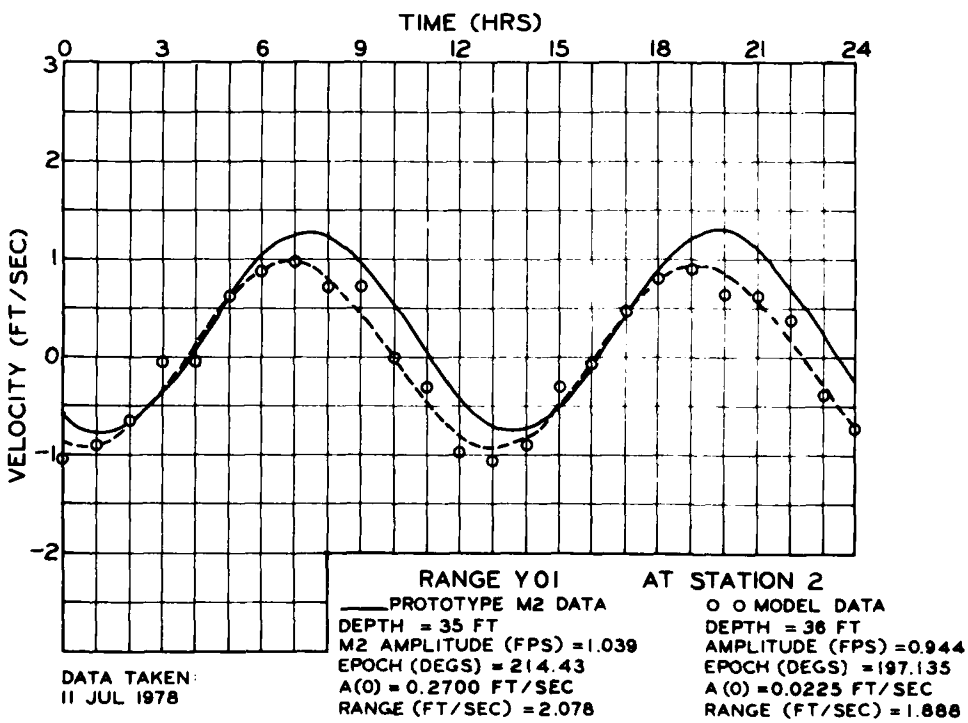
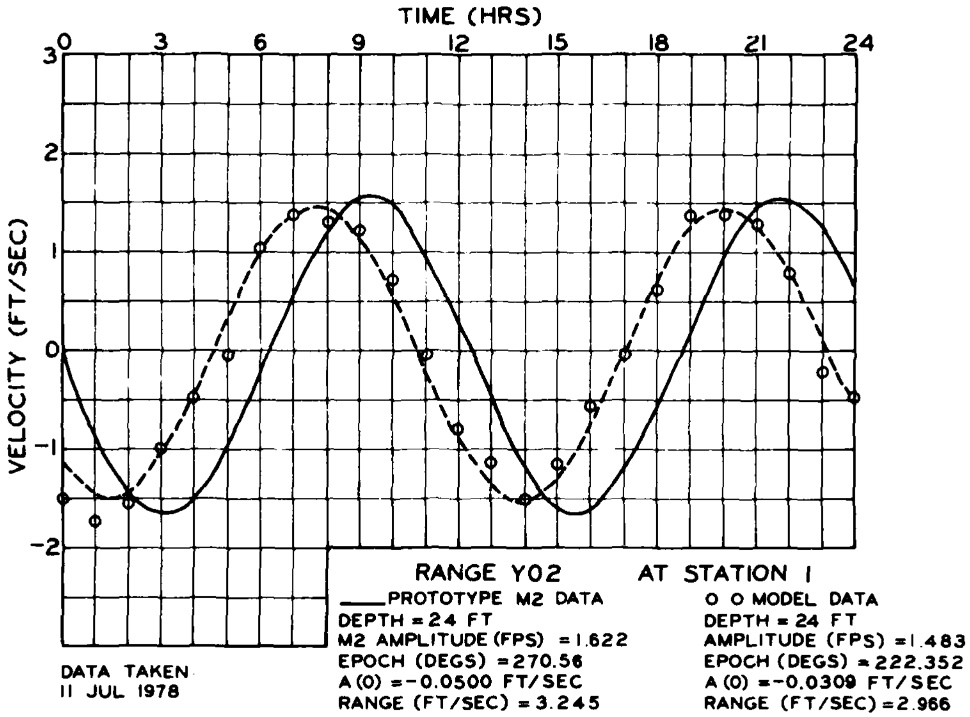




Plate C49. Model/prototype velocity comparison, Range Y01, sta 1 and 2



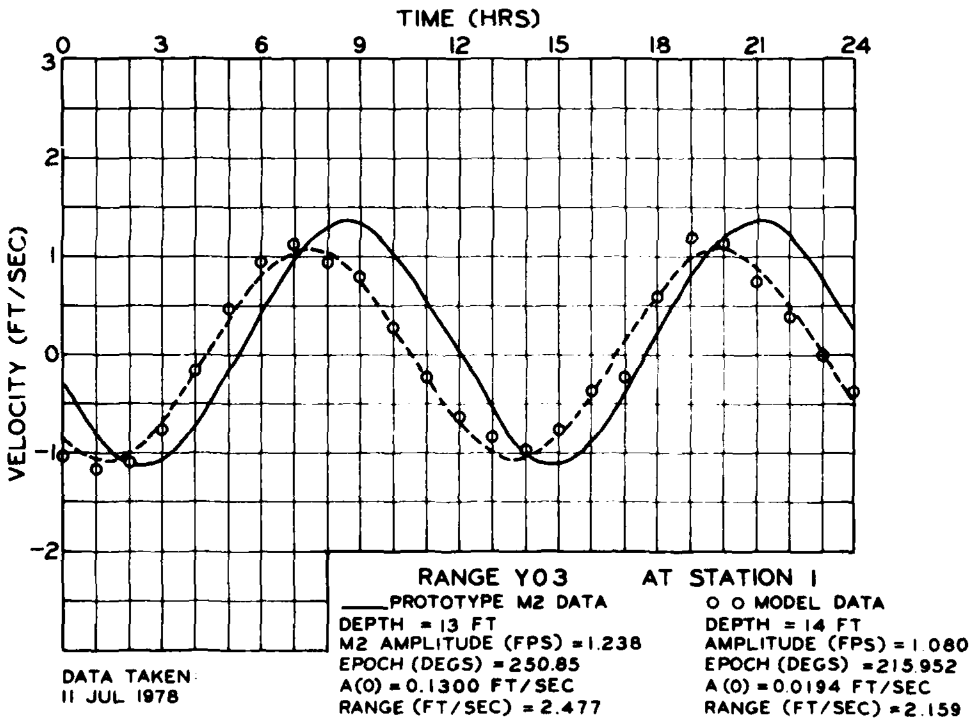
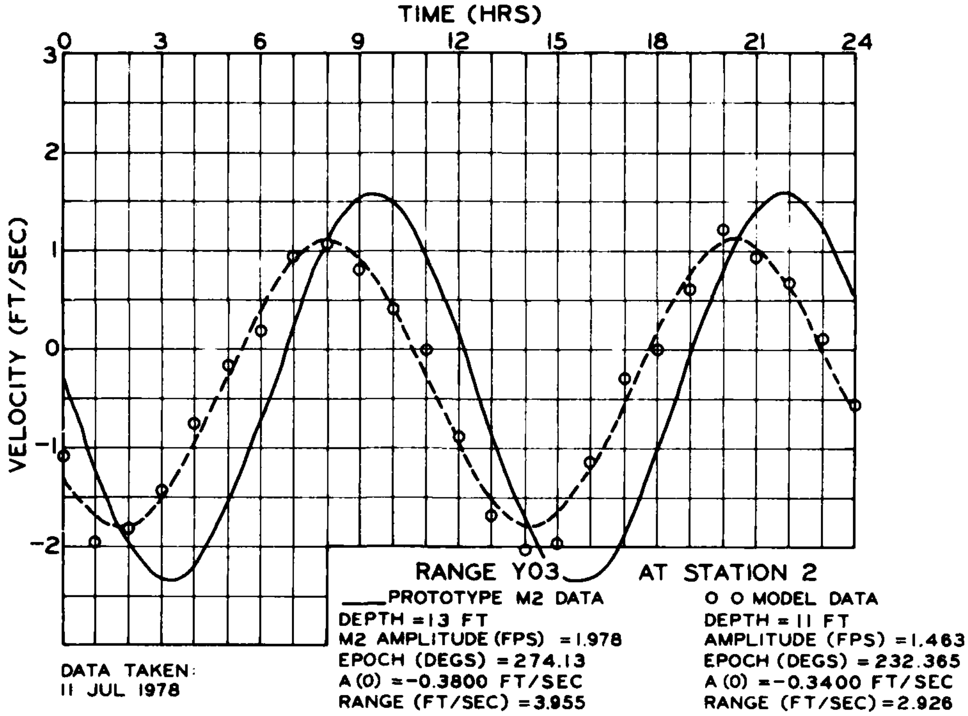




Plate C50. Model/prototype velocity comparison,
Range Y02, sta 1 and Range Y03, sta 1



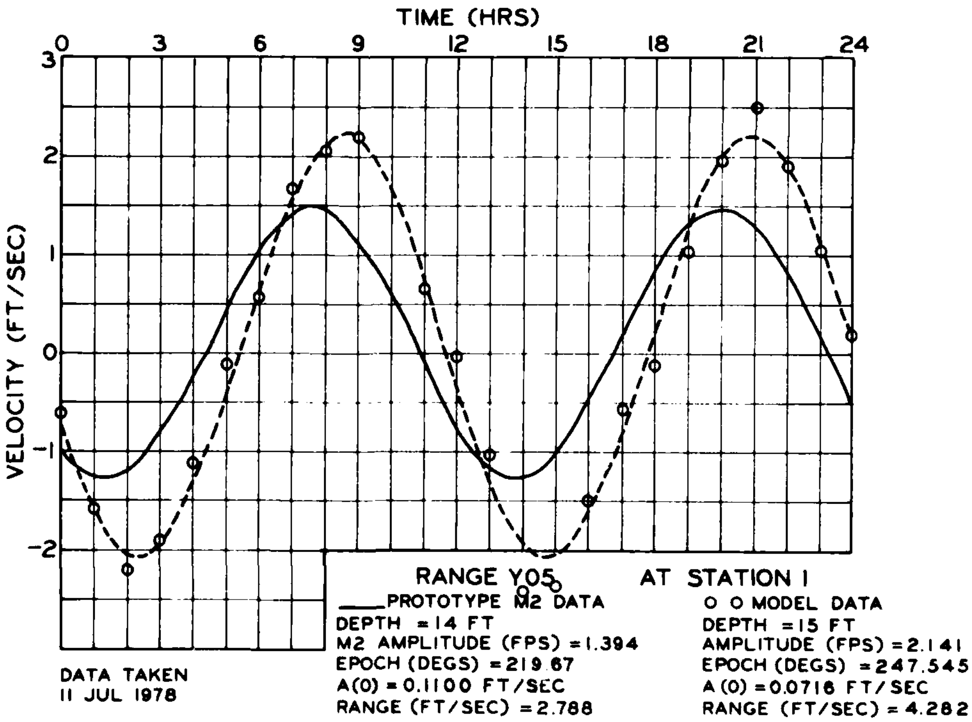
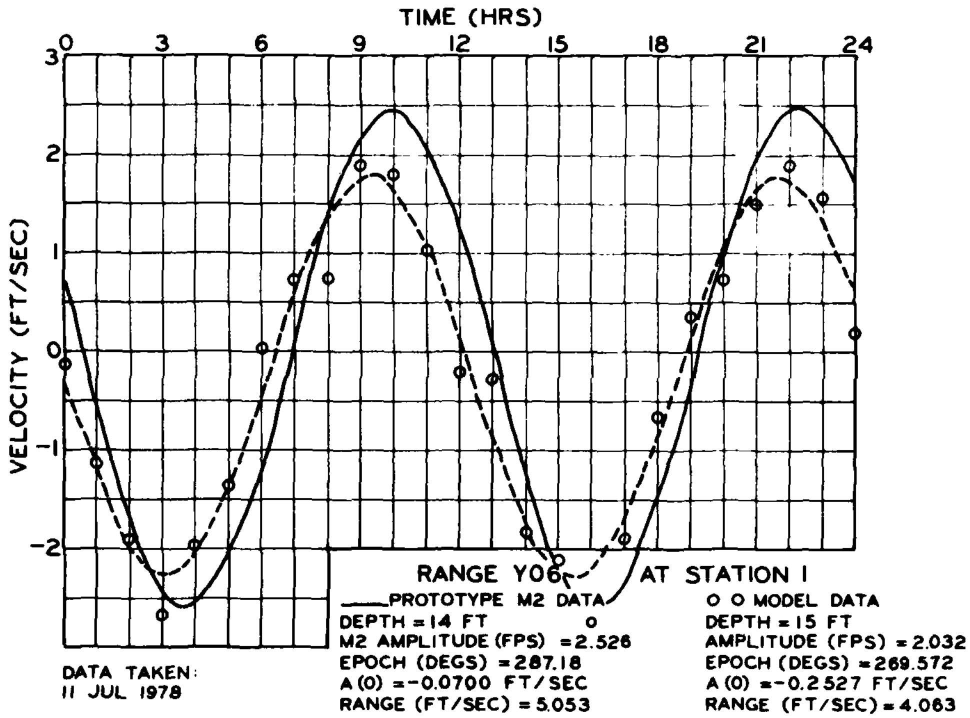




Plate C51. Model/prototype velocity comparison, Range Y03, sta 2 and Range Y05, sta 1



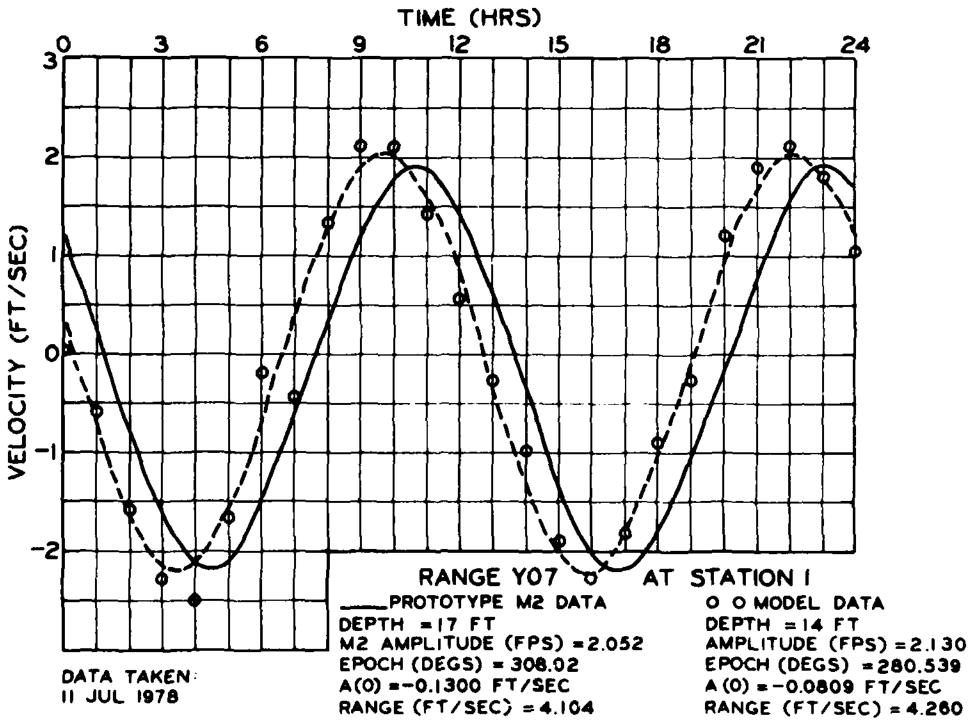




Plate C52. Model/prototype velocity comparison, Range Y06, sta 1 and Range Y07, sta 1

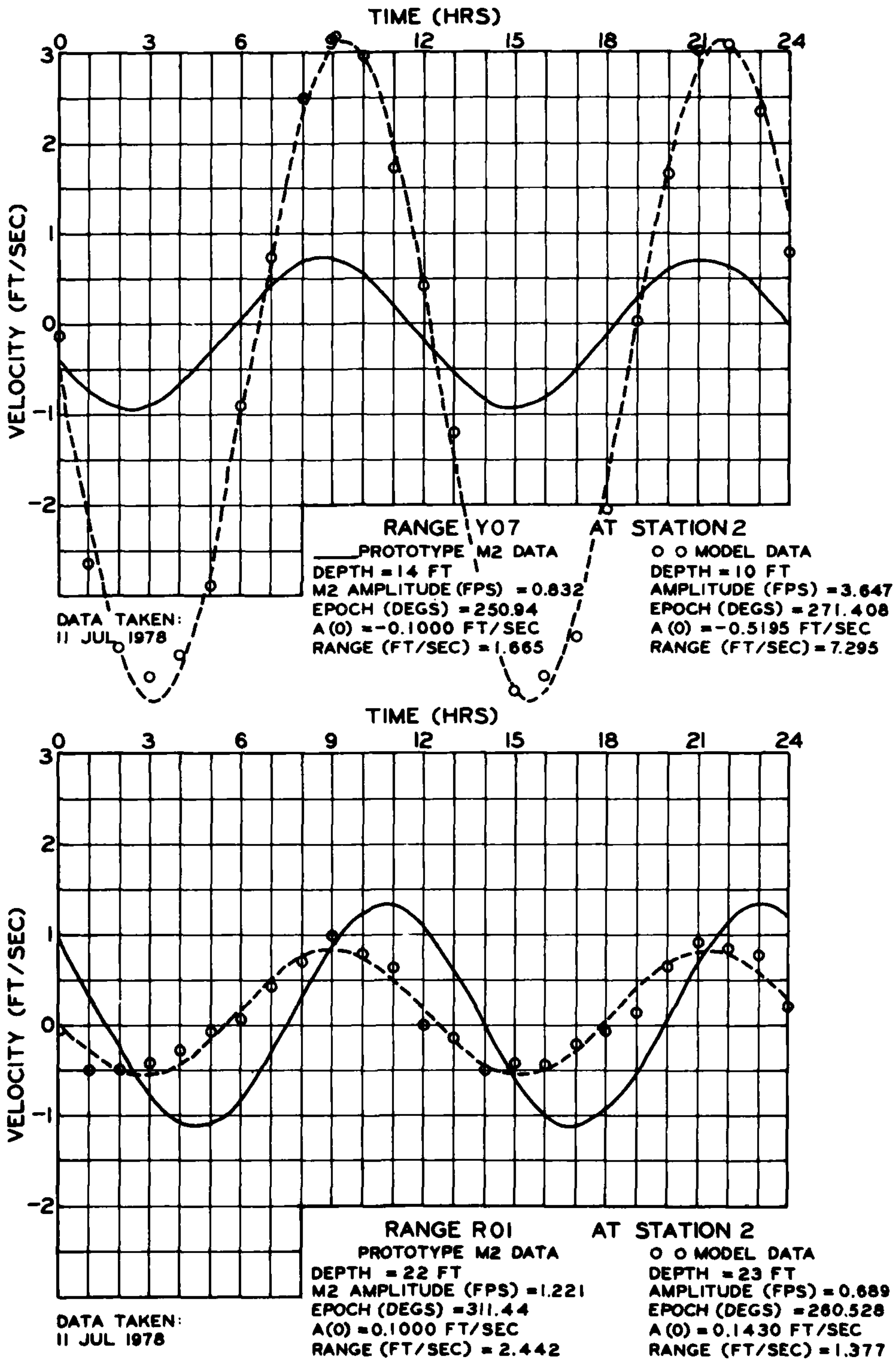
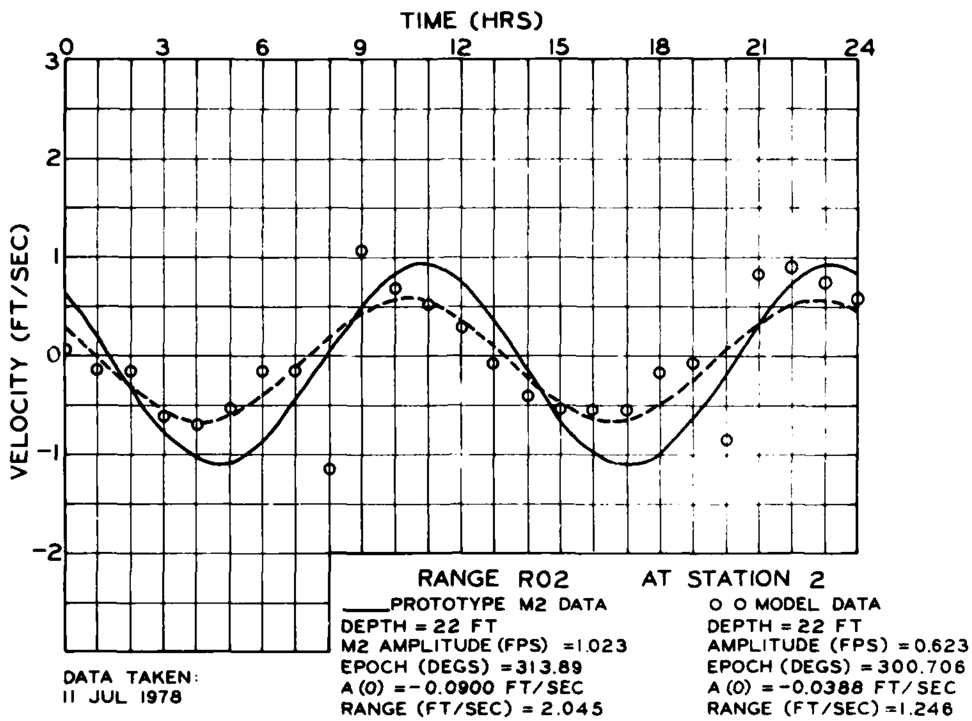



Plate C53. Model/prototype velocity comparison, Range Y07, sta 2 and Range R01, sta 2



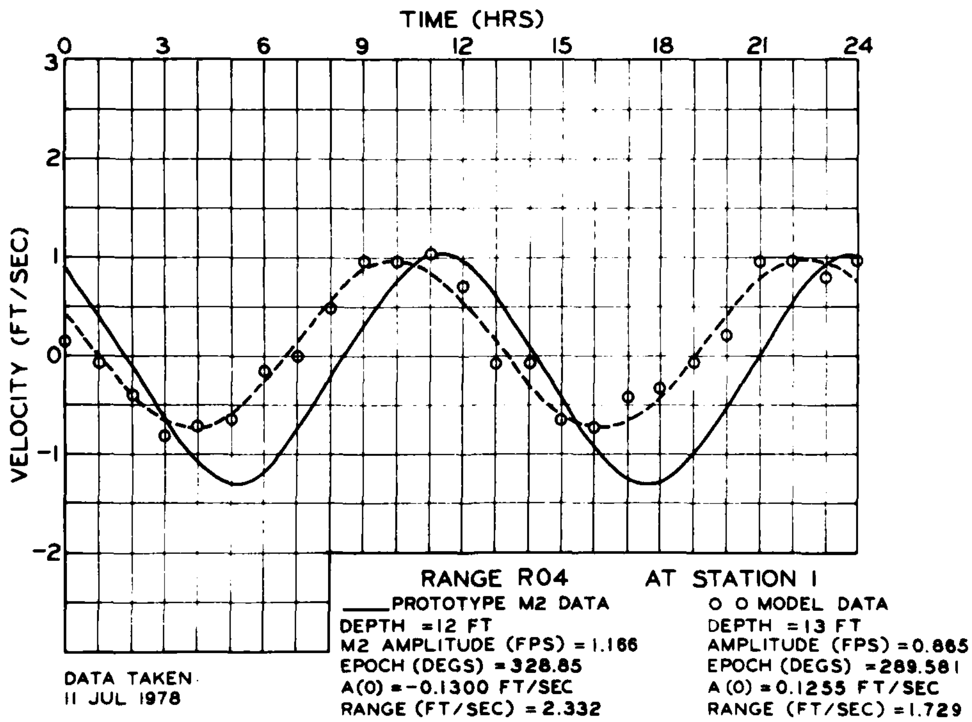
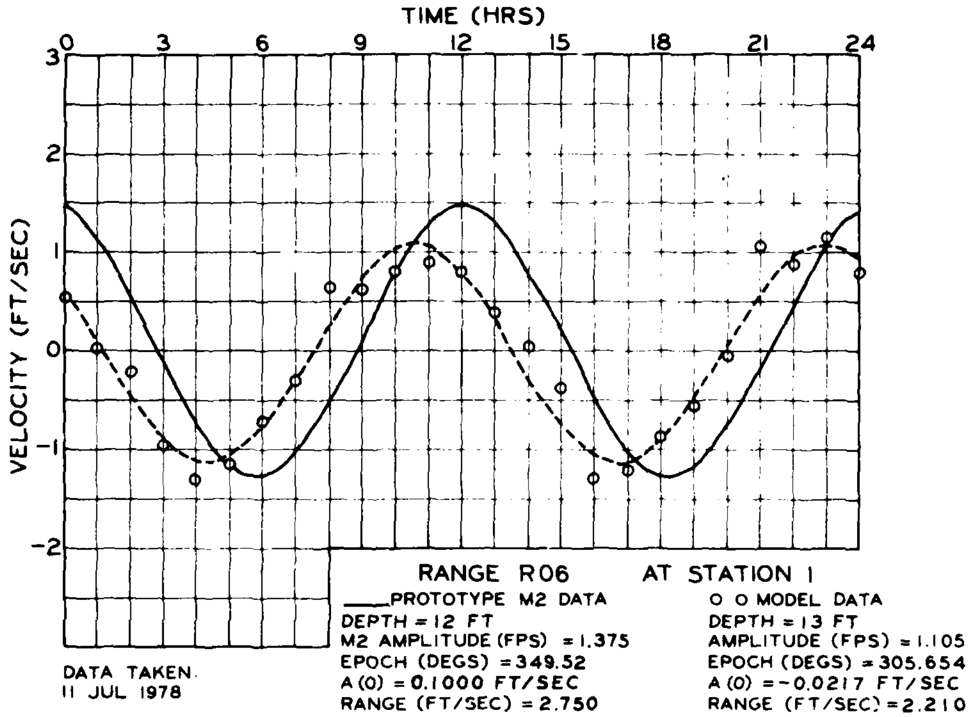




Plate C54. Model/prototype velocity comparison, Range R02, sta 2 and Range R04, sta 1



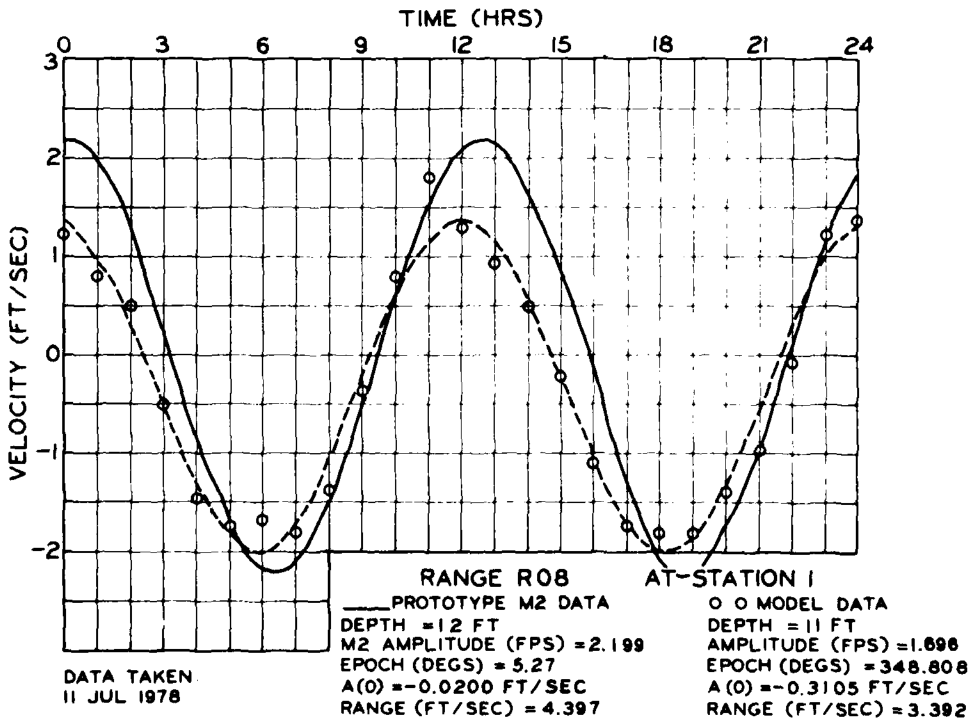
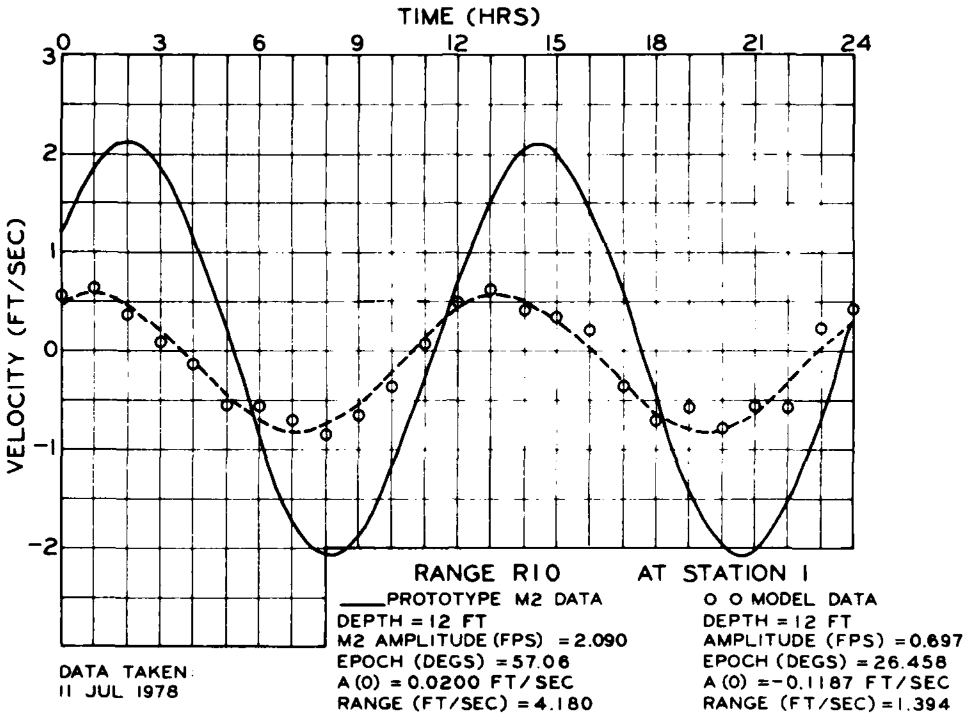




Plate C55. Model/prototype velocity comparison, Range R06, sta 1 and Range R08, sta 1



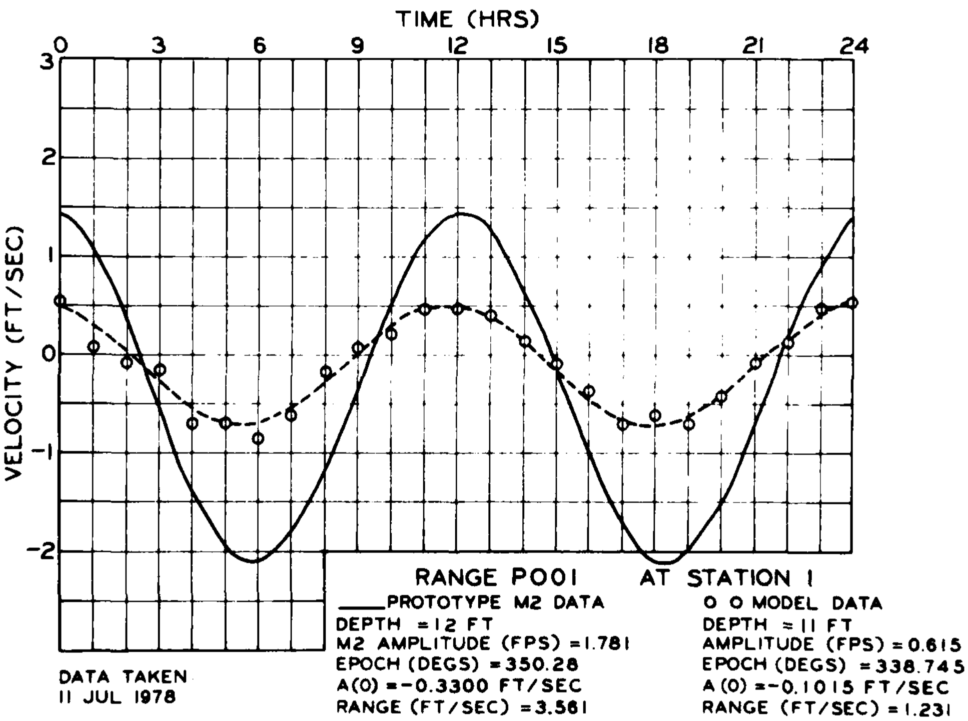
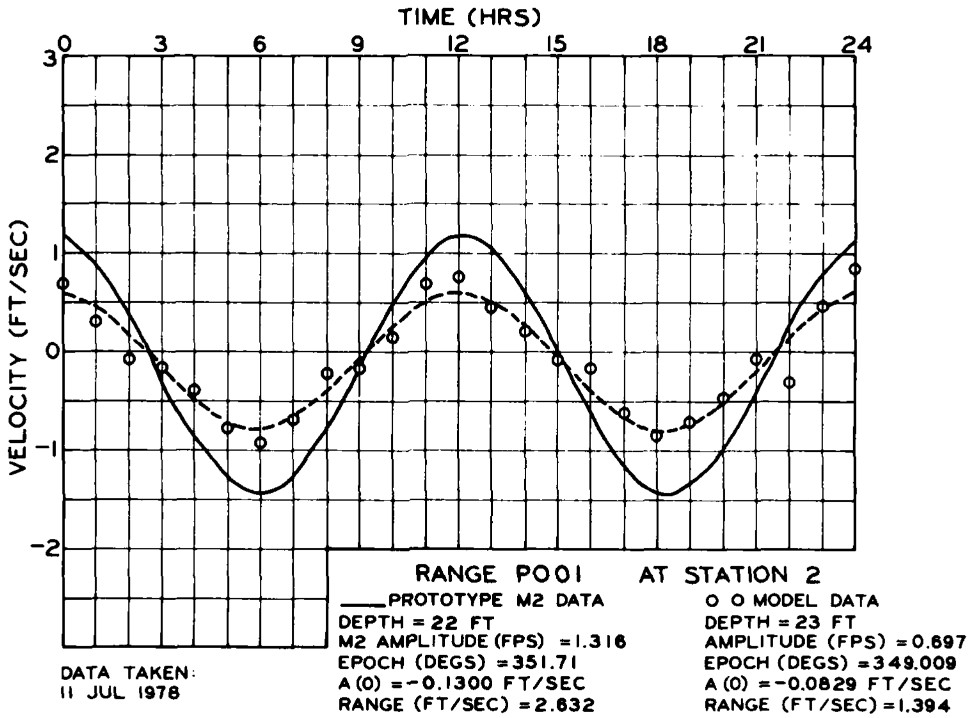




Plate C56. Model/prototype velocity comparison,
Range R10, sta 1 and Range P001, sta 1



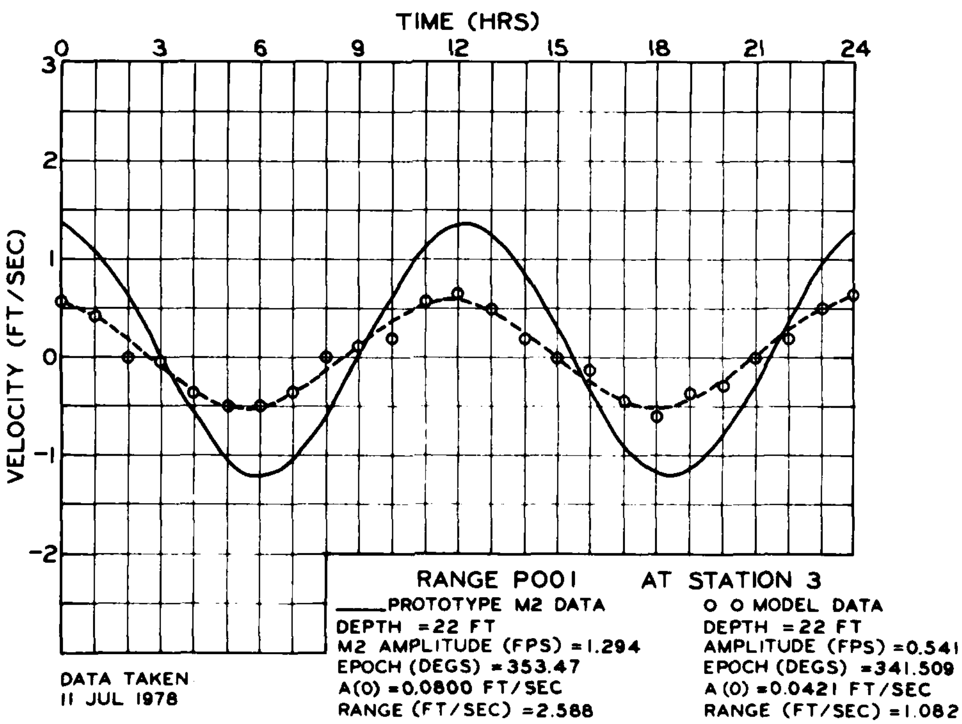
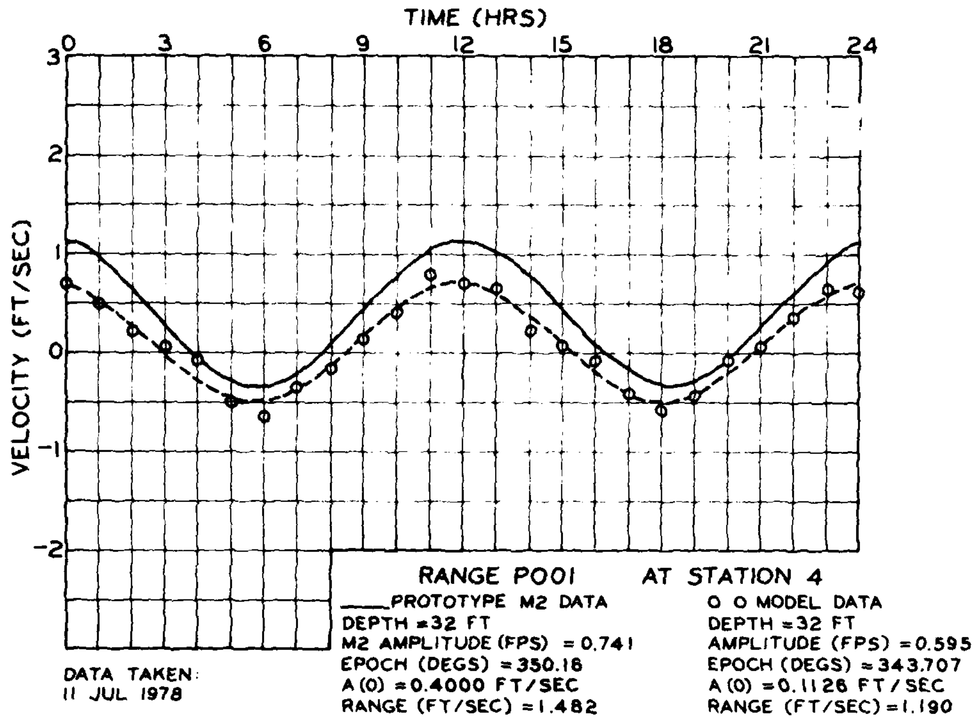




Plate C57. Model/prototype velocity comparison, Range Pool, sta 2 and 3



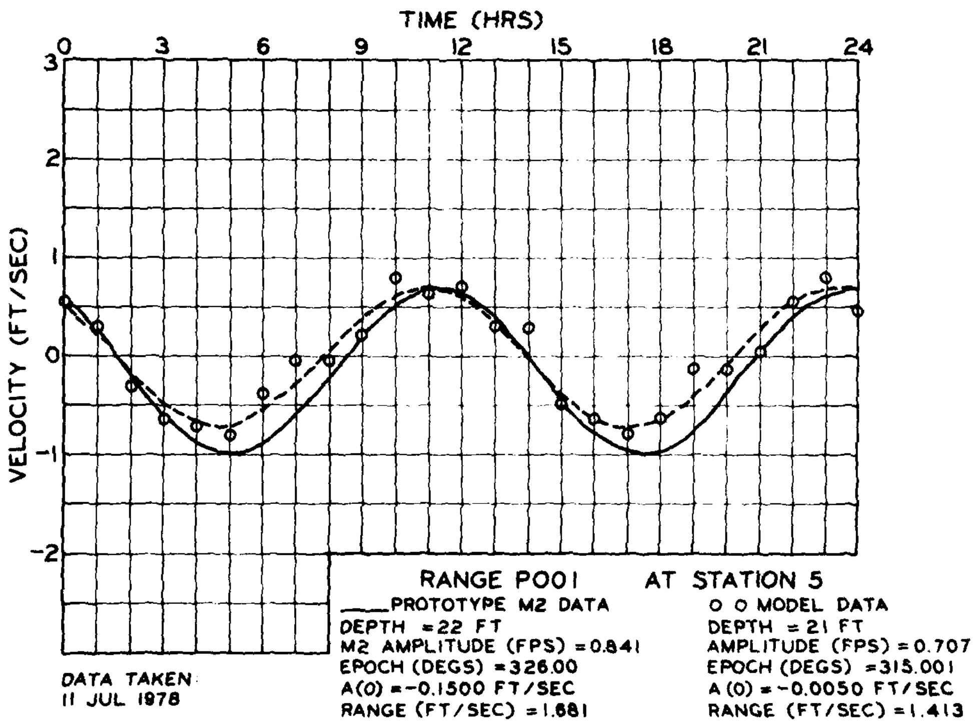
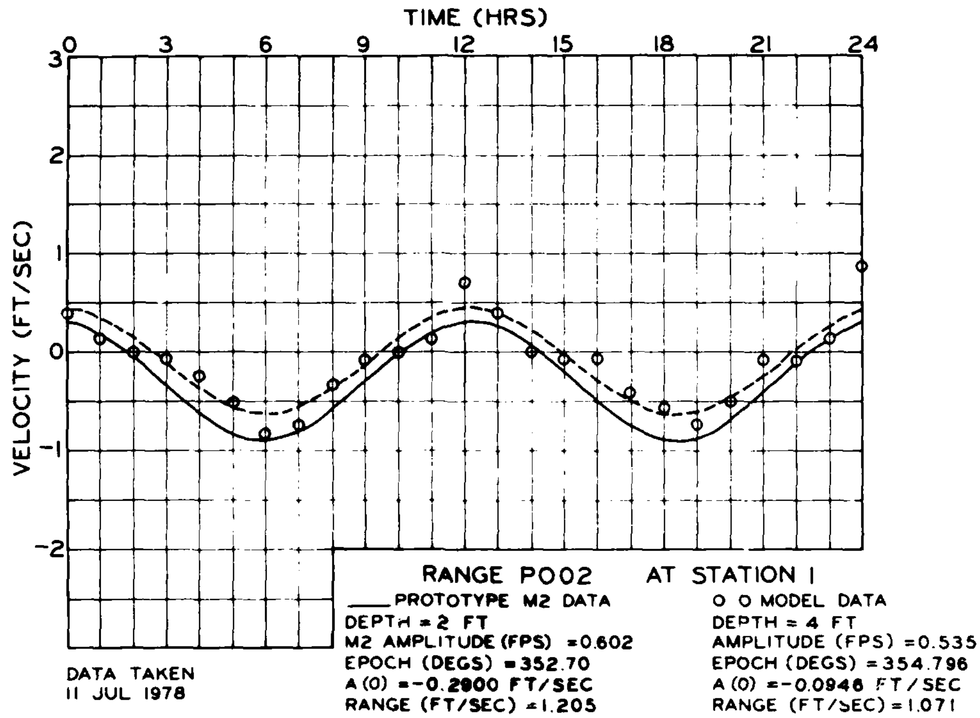




Plate C58. Model/prototype velocity comparison, Range P001, sta 4 and 5



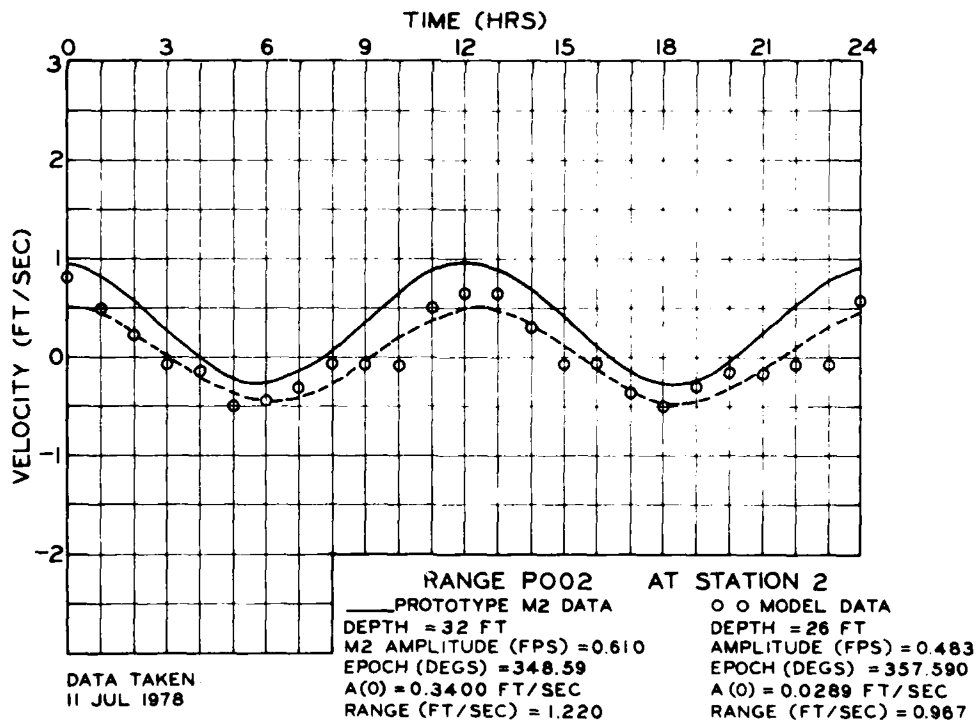
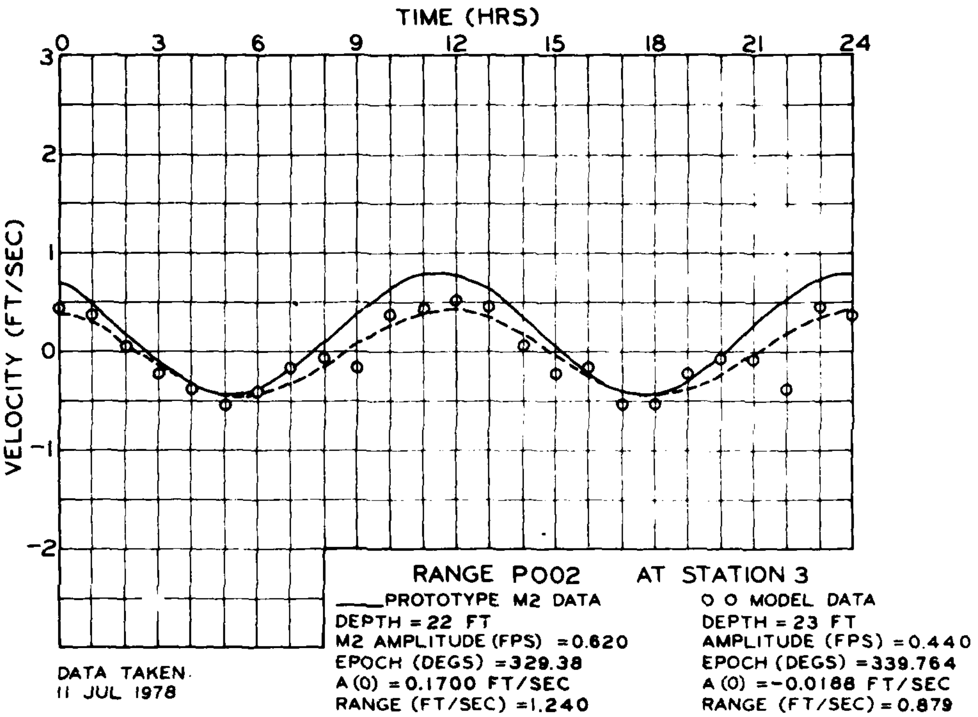




Plate C59. Model/prototype velocity comparison,
Range P002, sta 1 and 2



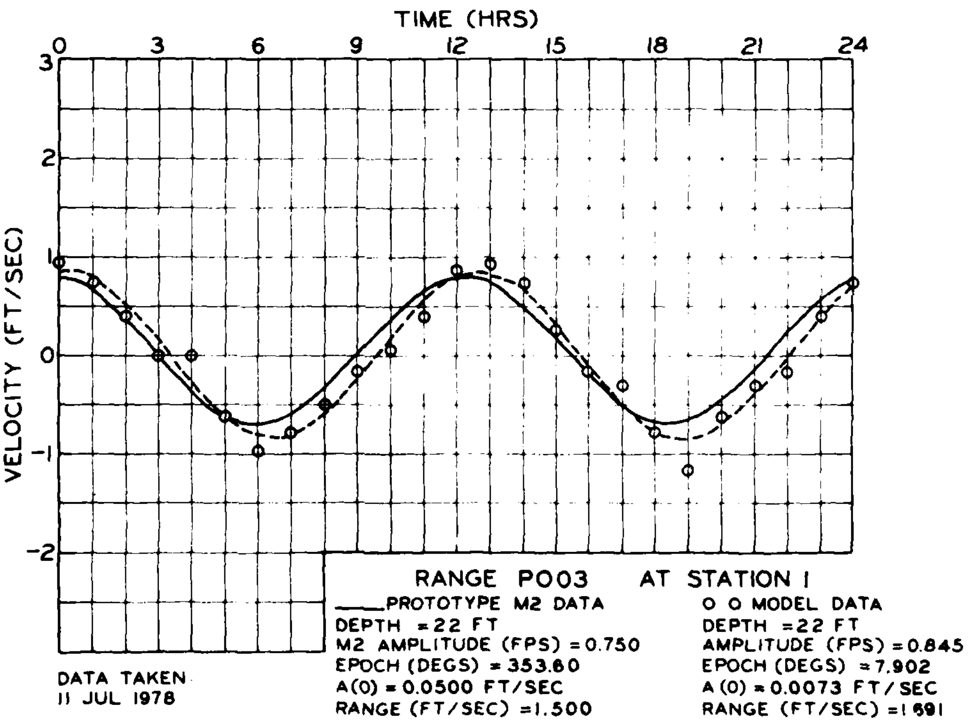
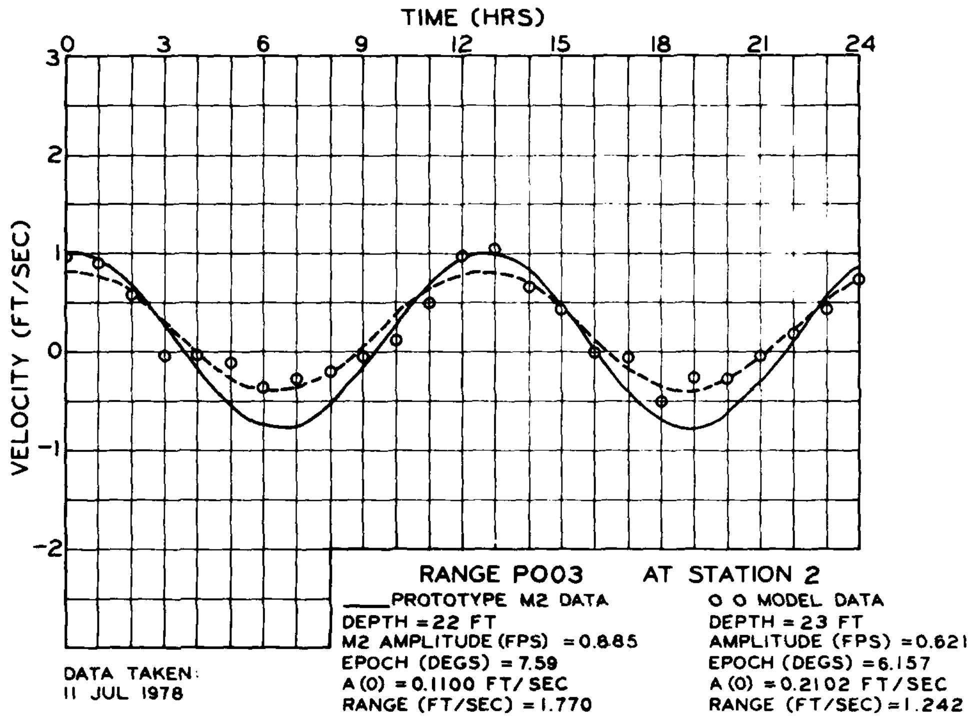




Plate C60. Model/prototype velocity comparison, Range P002, sta 3 and Range P003, sta 1



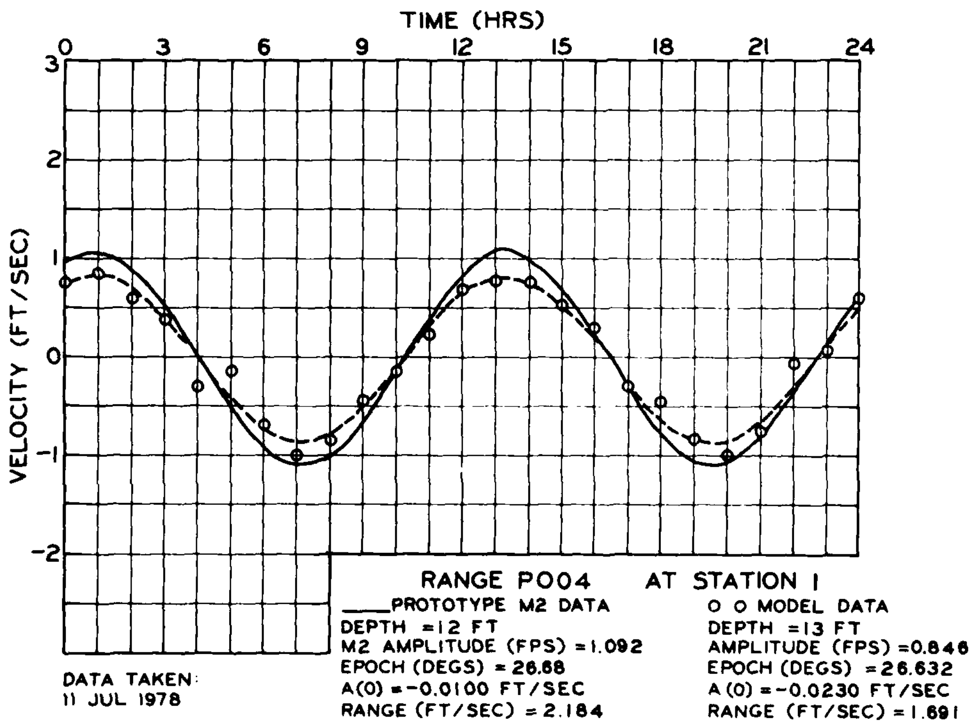
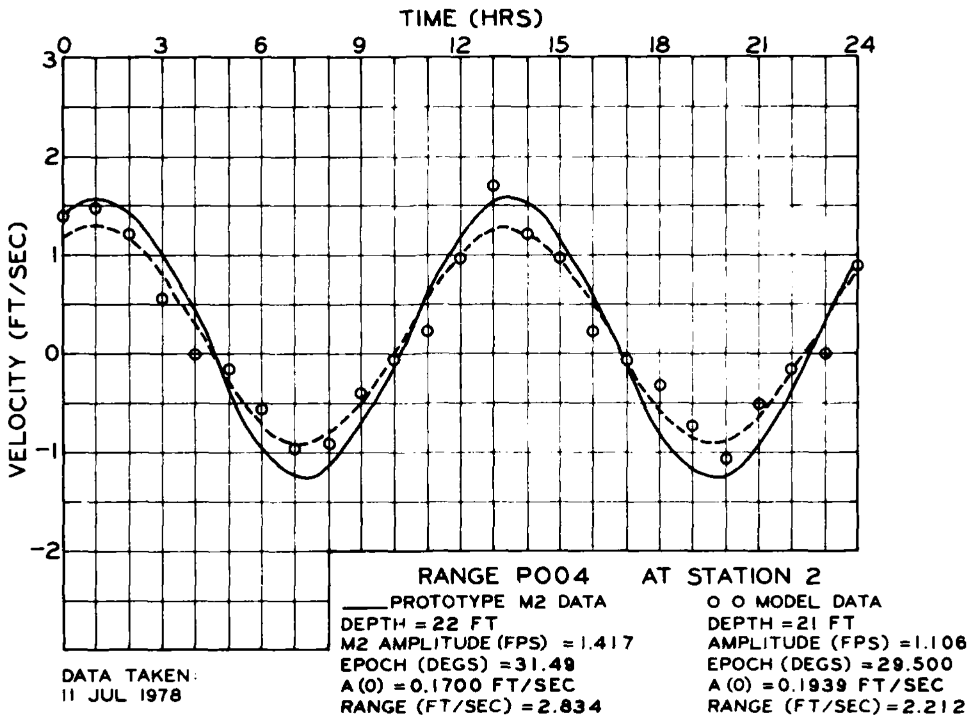




Plate C61. Model/prototype velocity comparison,
Range P003, sta 2 and Range P004, sta 1



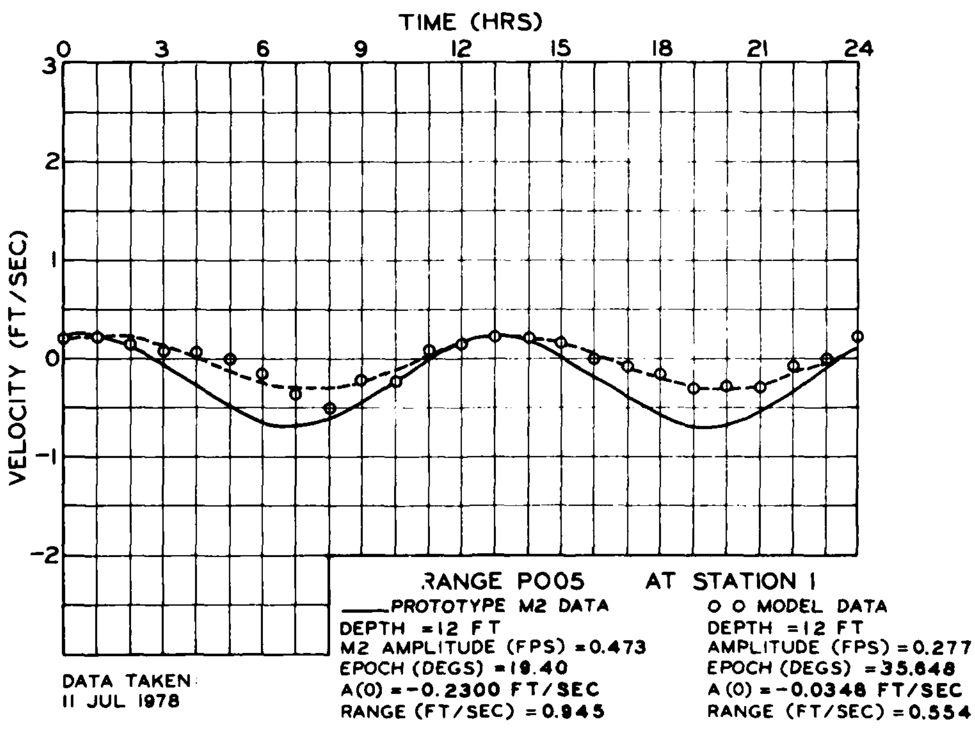
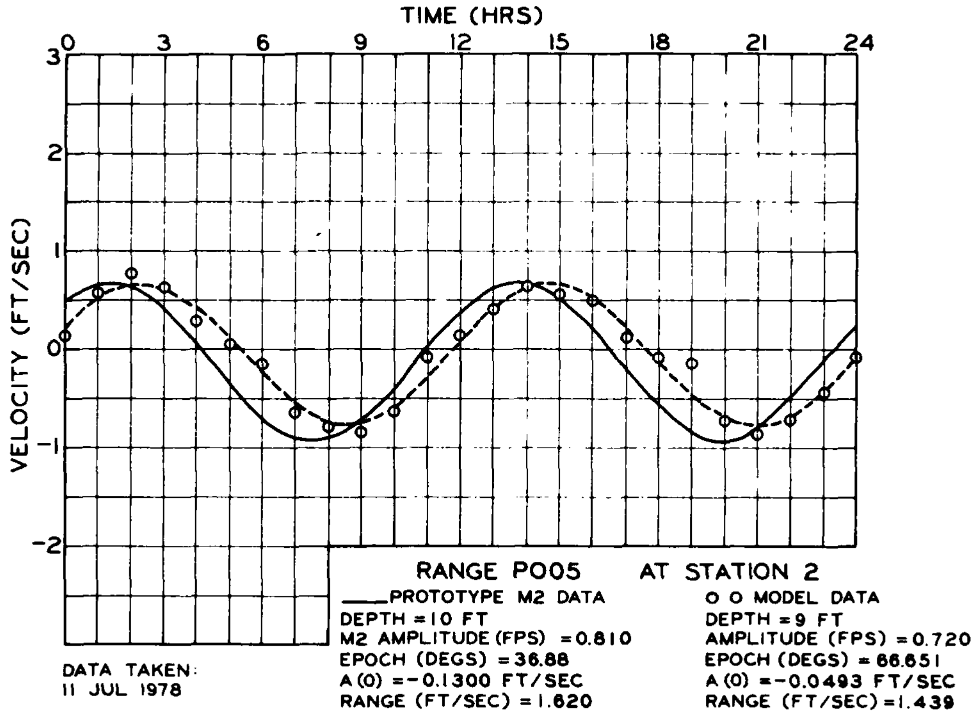




Plate C62. Model/prototype velocity comparison,
Range P004, sta 2 and Range P005, sta 1



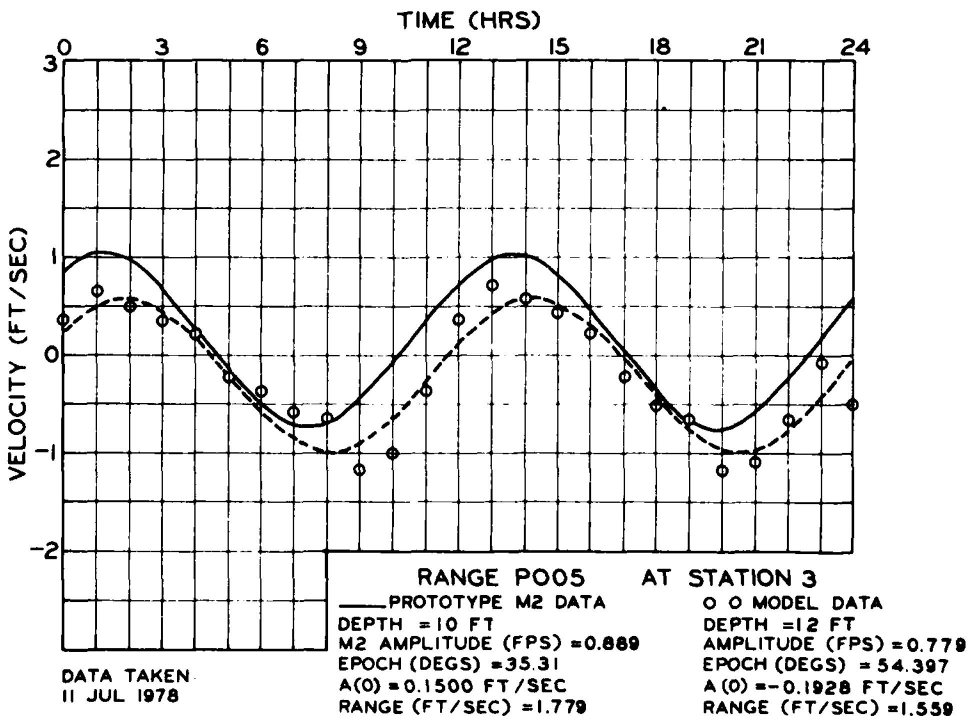
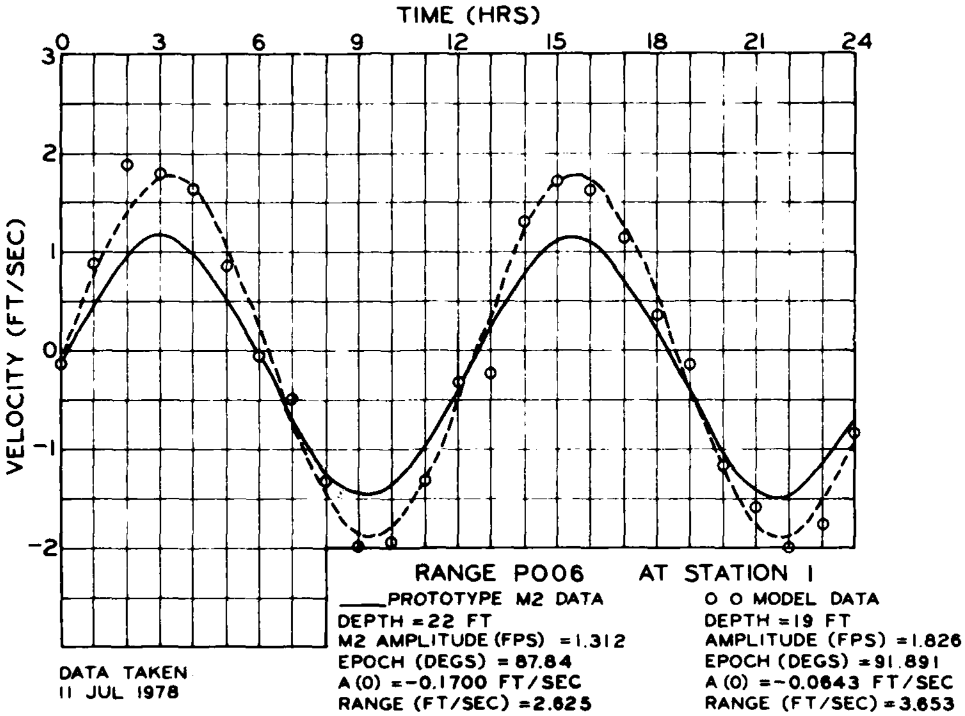




Plate C63. Model/prototype velocity comparison, Range P005, sta 2 and 3



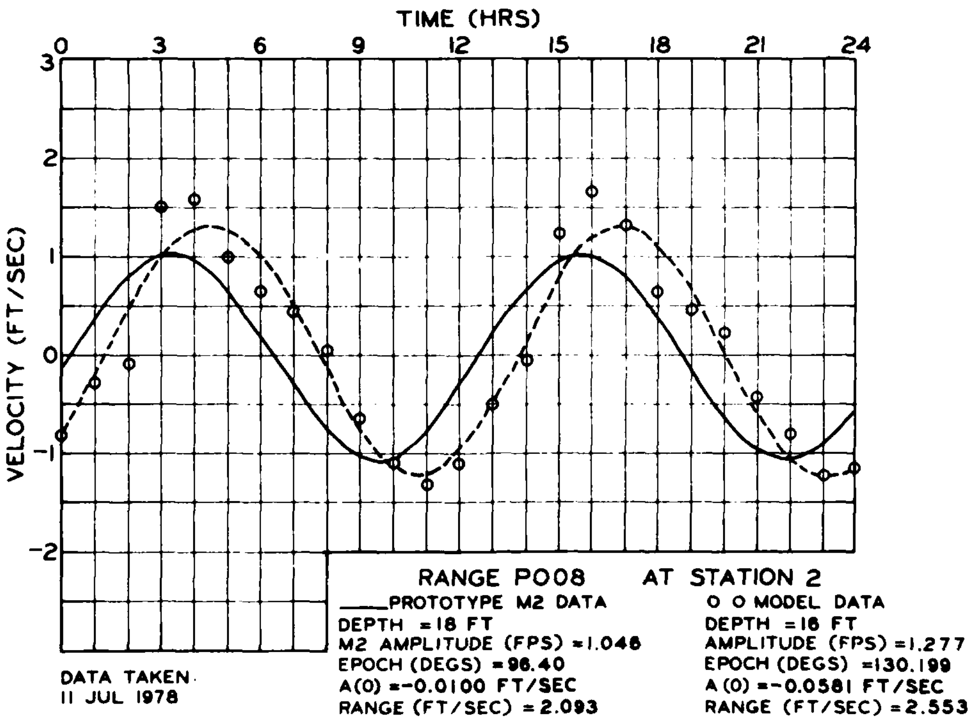
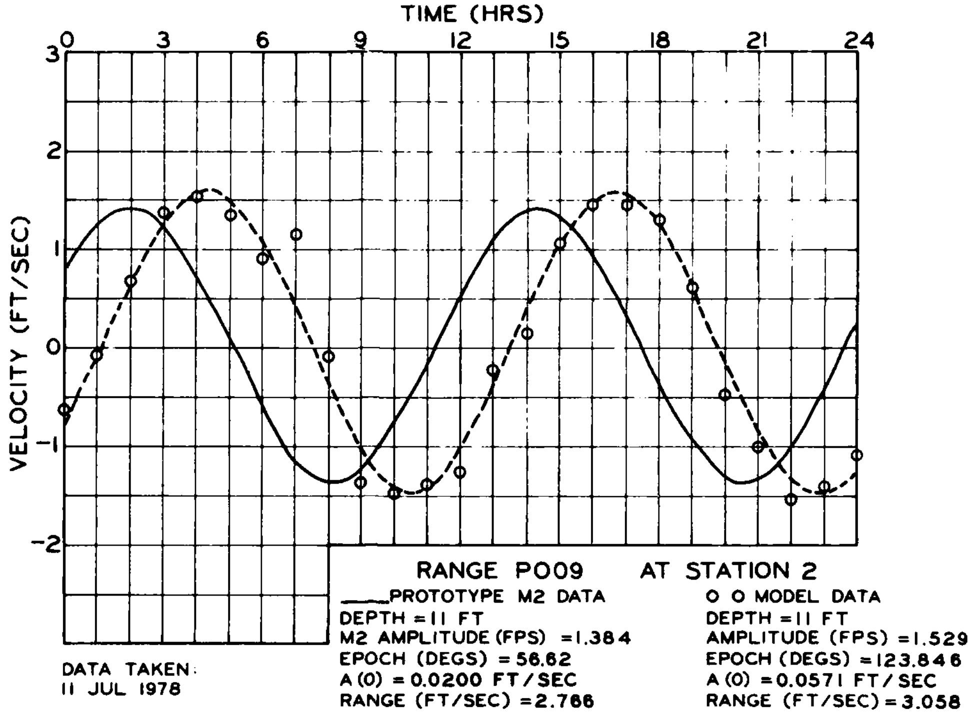




Plate C64. Model/prototype velocity comparison,
Range P006, sta 1 and Range P008, sta 2



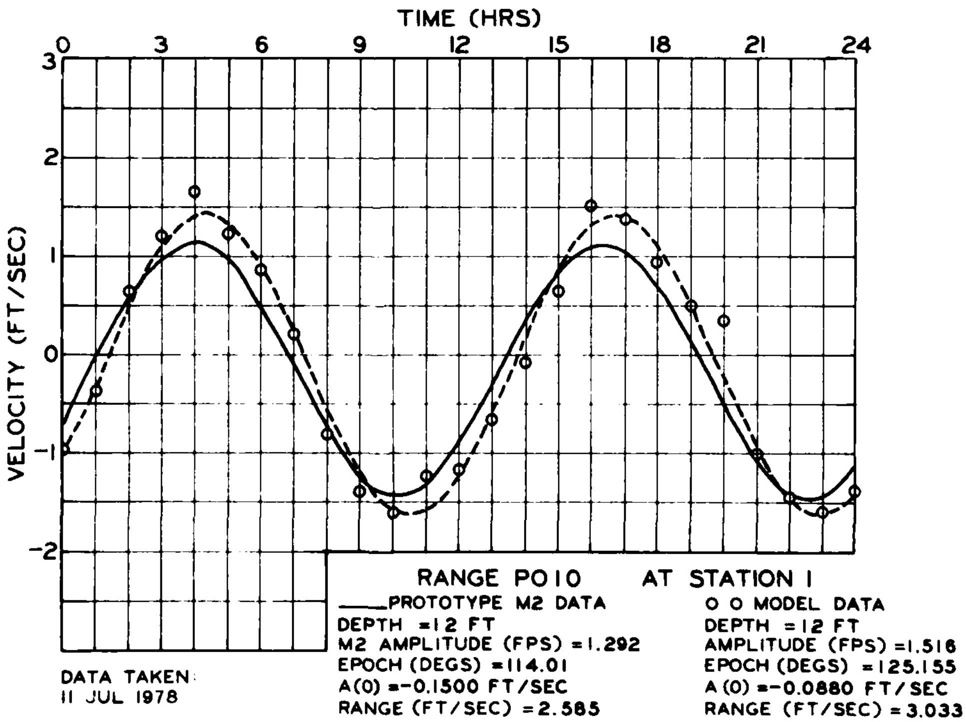
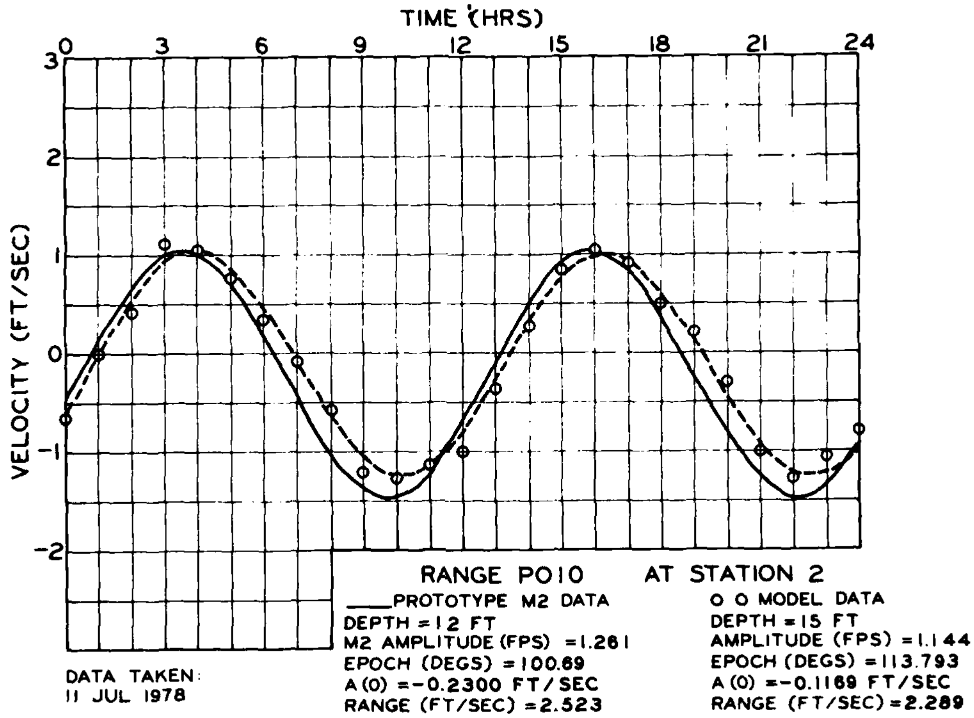




Plate C65. Model/prototype velocity comparison, Range P009, sta 2 and Range P010, sta 1



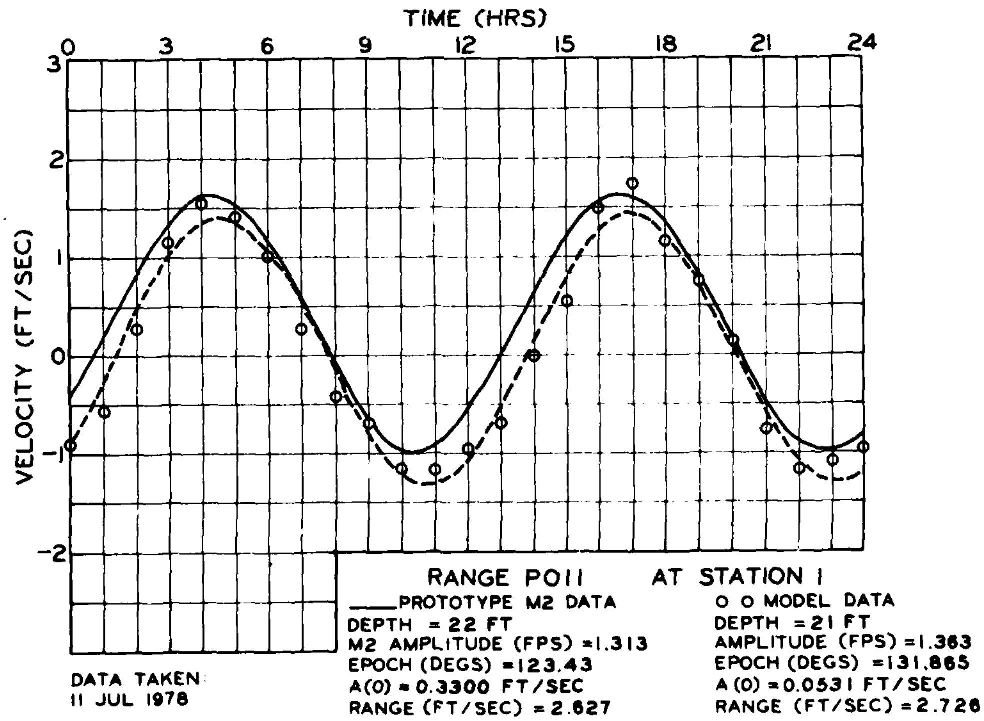
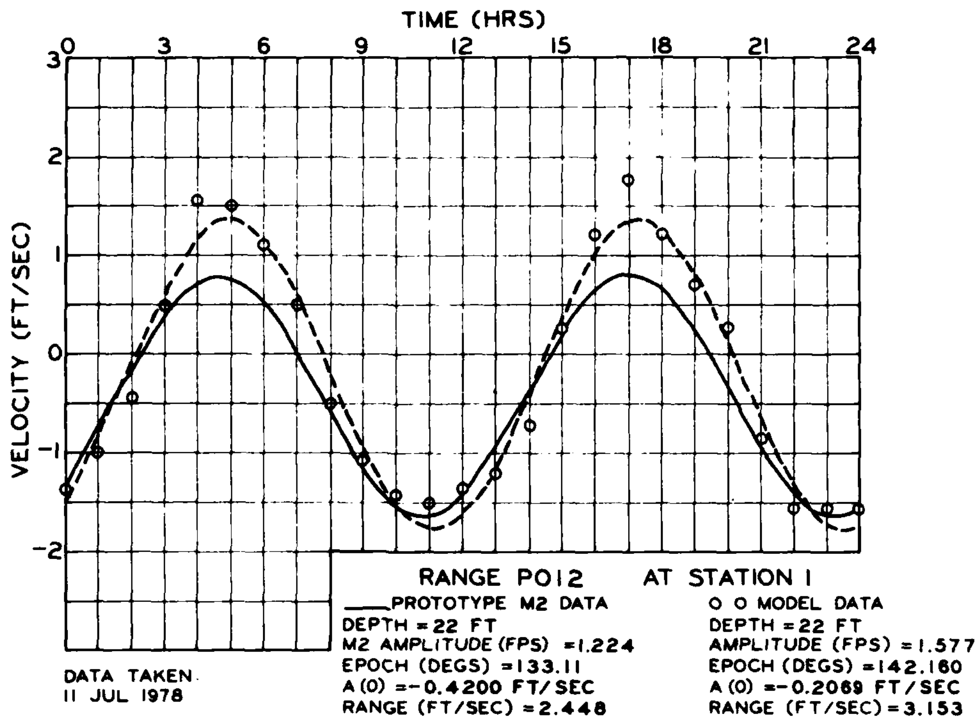




Plate C66. Model/prototype velocity comparison, Range P010, sta 2 and Range P011, sta 1



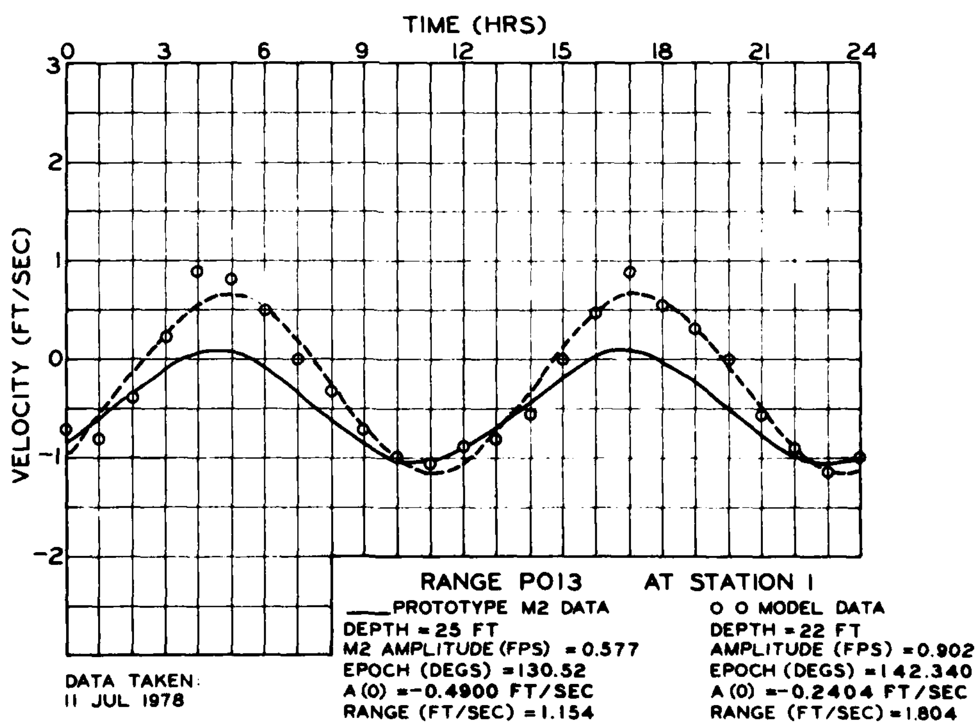
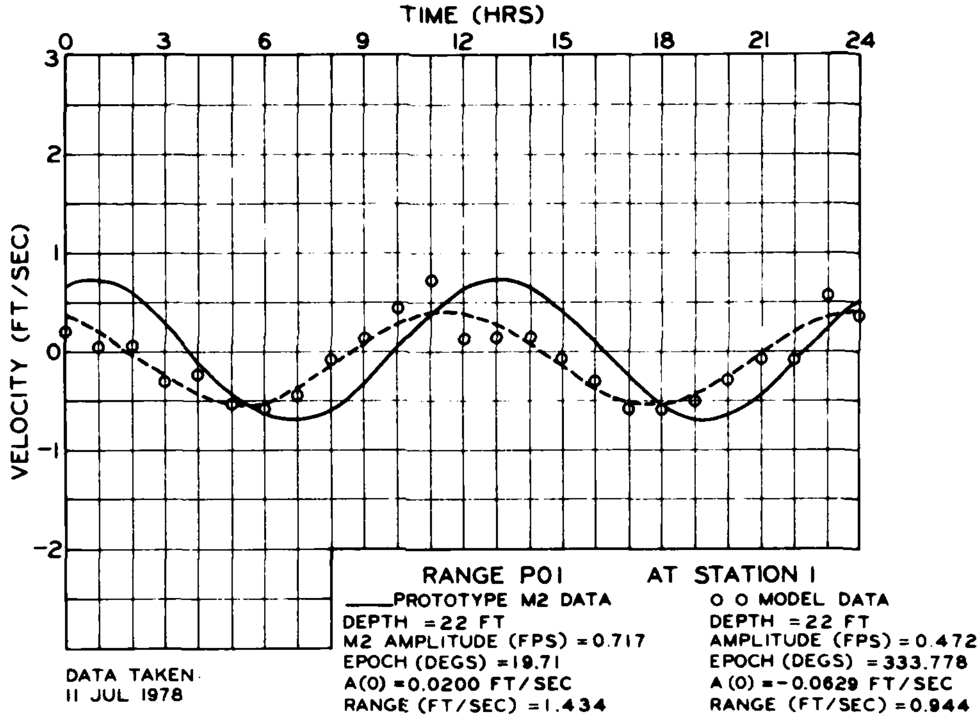




Plate C67. Model/prototype velocity comparison, Range P012, sta 1 and Range P013, sta 1



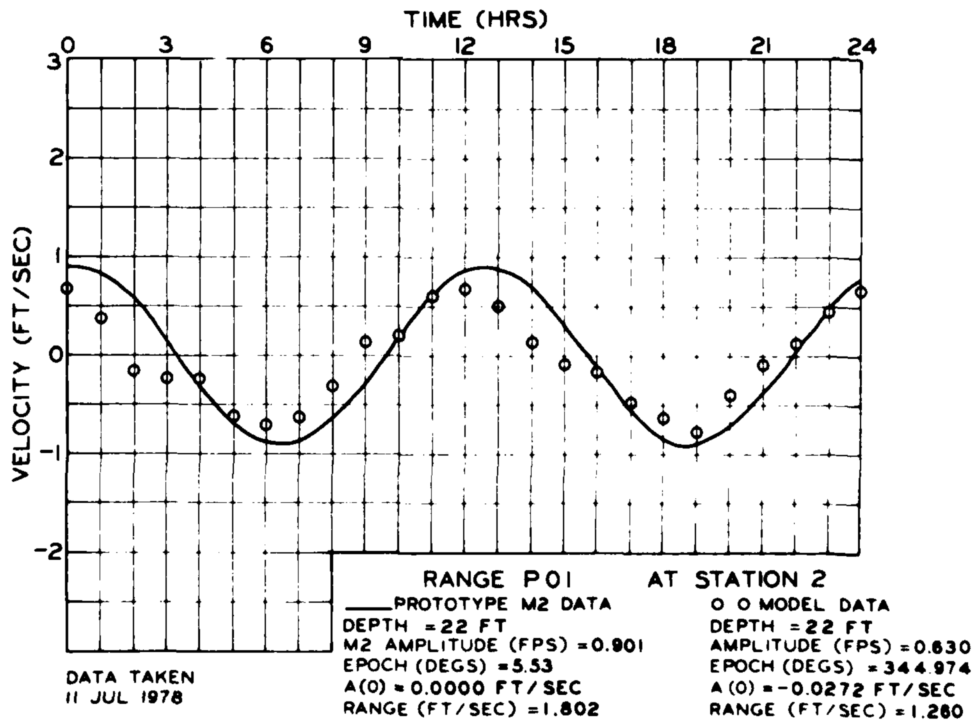
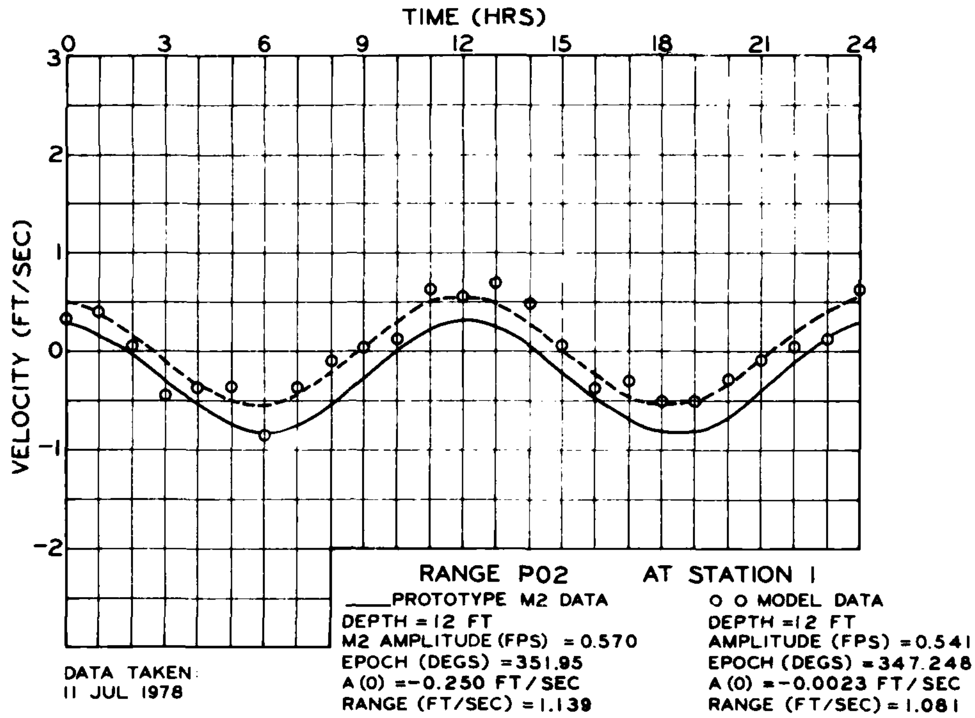




Plate C68. Model/prototype velocity comparison, Range P01, sta 2 and Range P01, sta 1



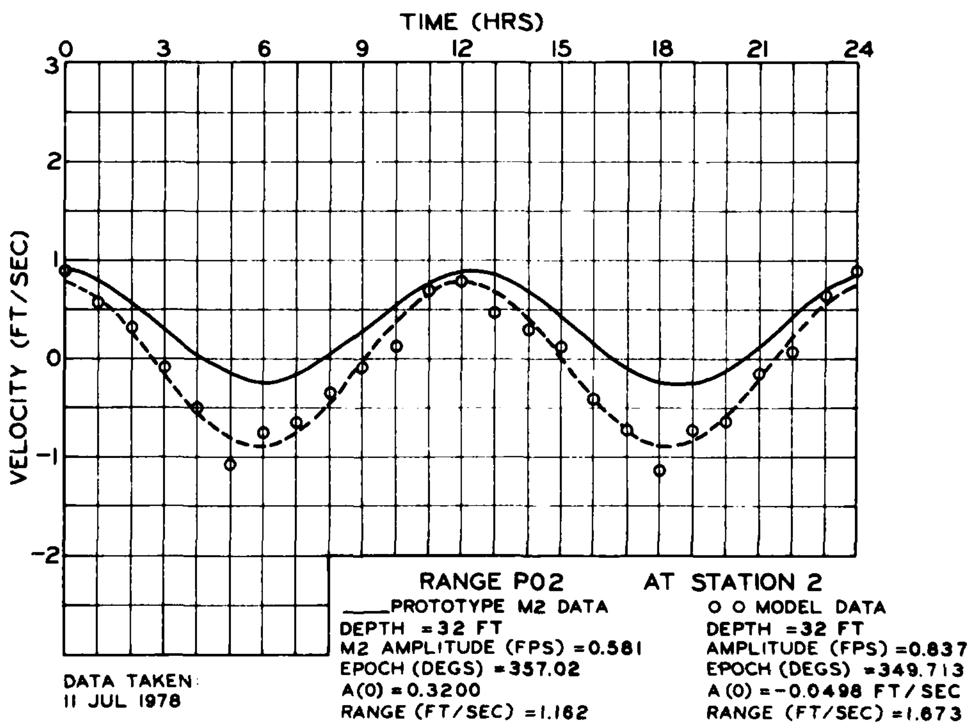
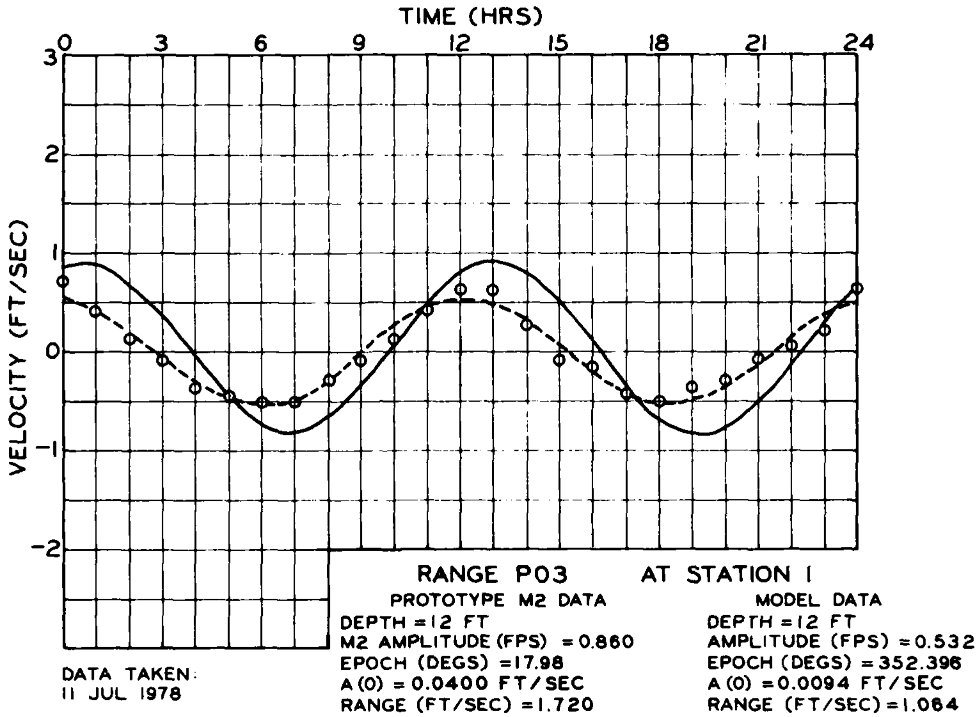




Plate C69. Model/prototype velocity comparison, Range P02, sta 1 and 2



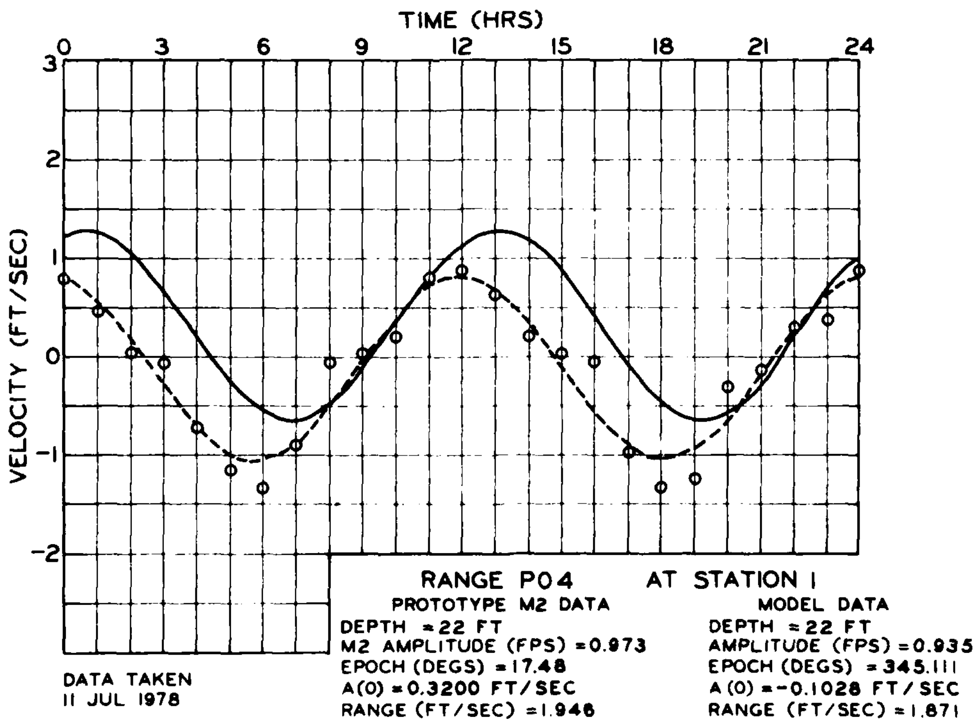
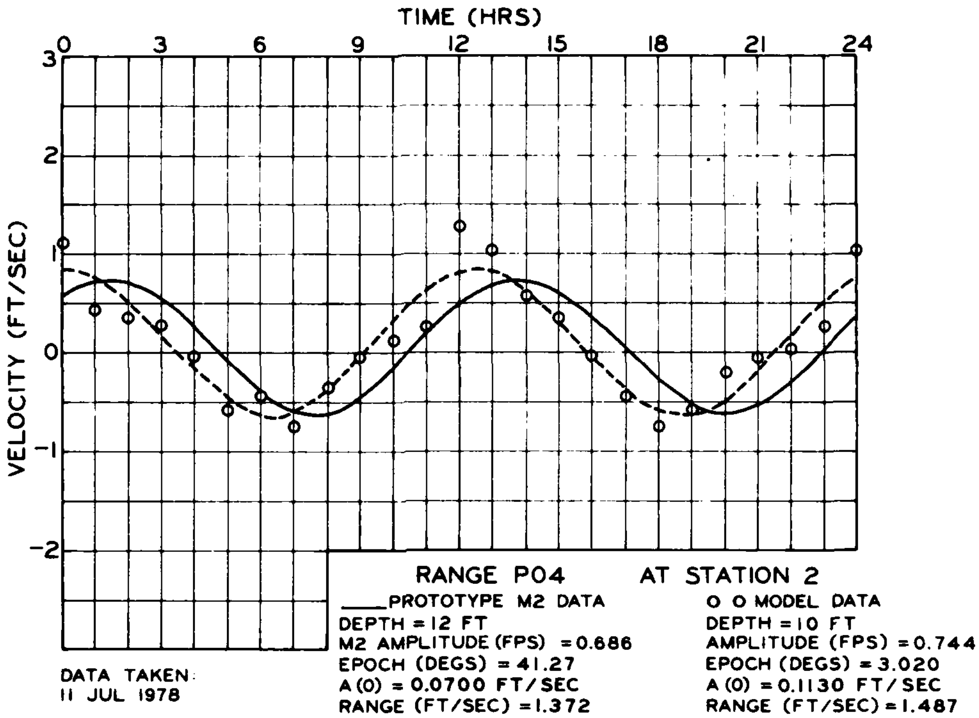




Plate C70. Model/prototype velocity comparison,
Range P03, sta 1 and Range P04, sta 1



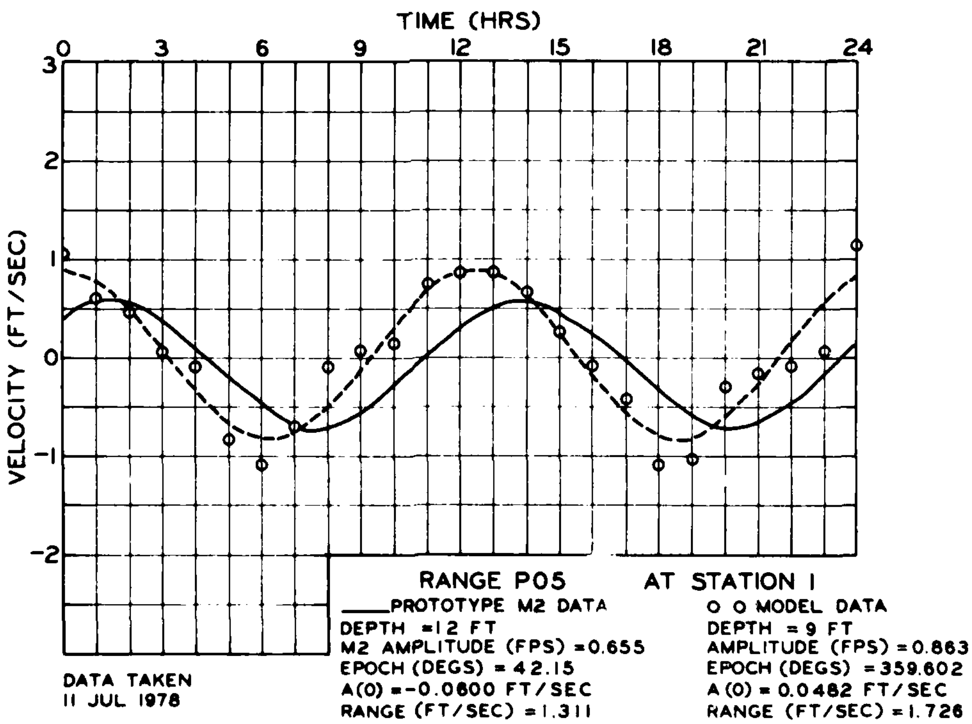
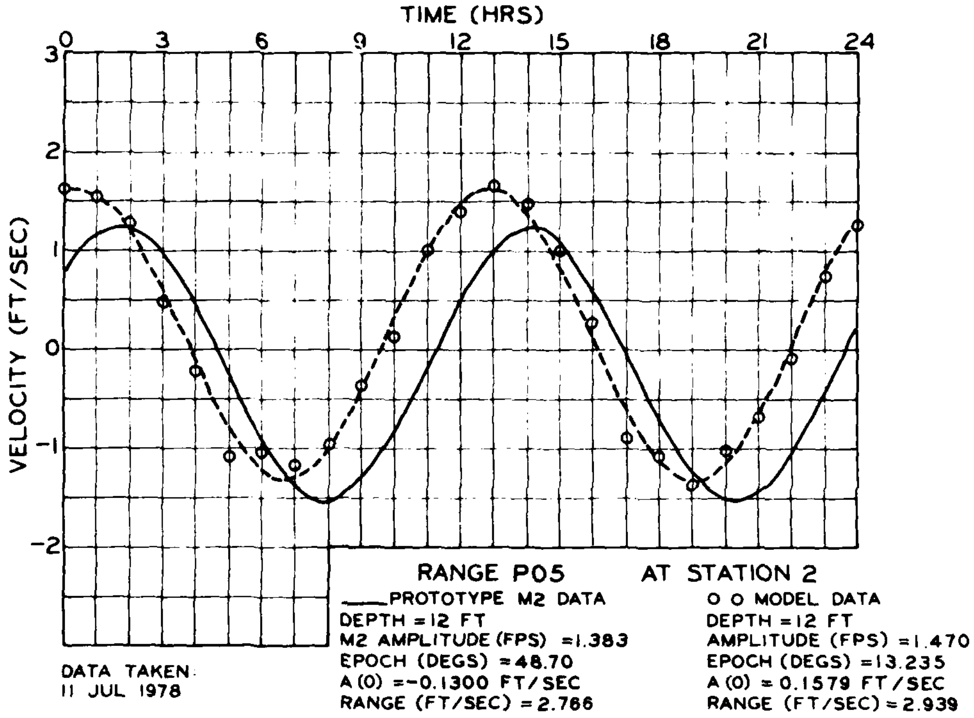




Plate C71. Model/prototype velocity comparison, Range P04, sta 2 and Range P05, sta 1



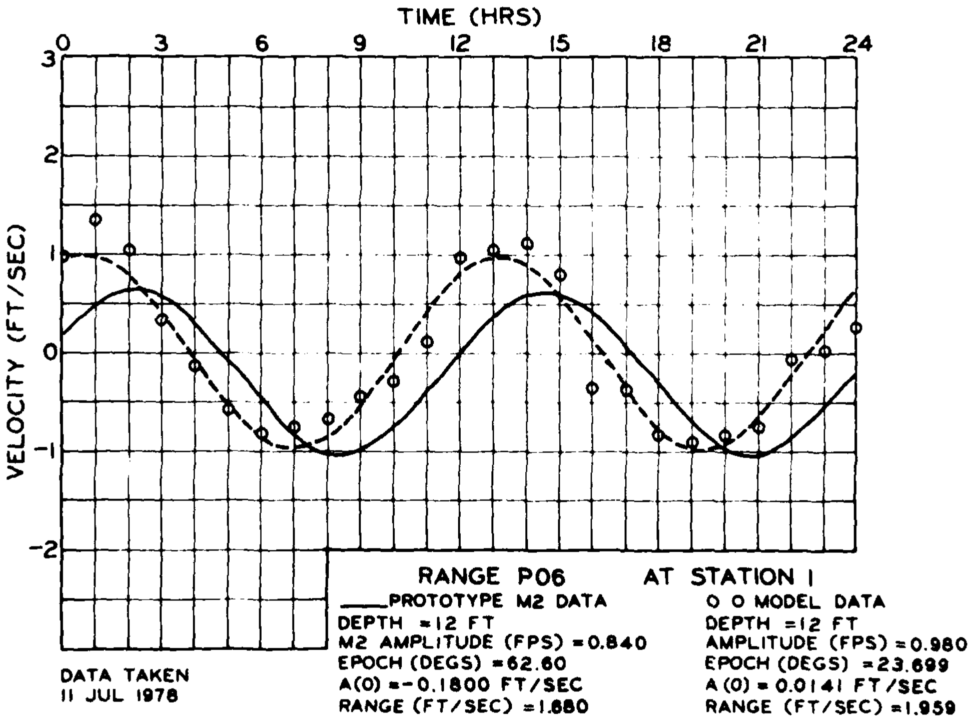
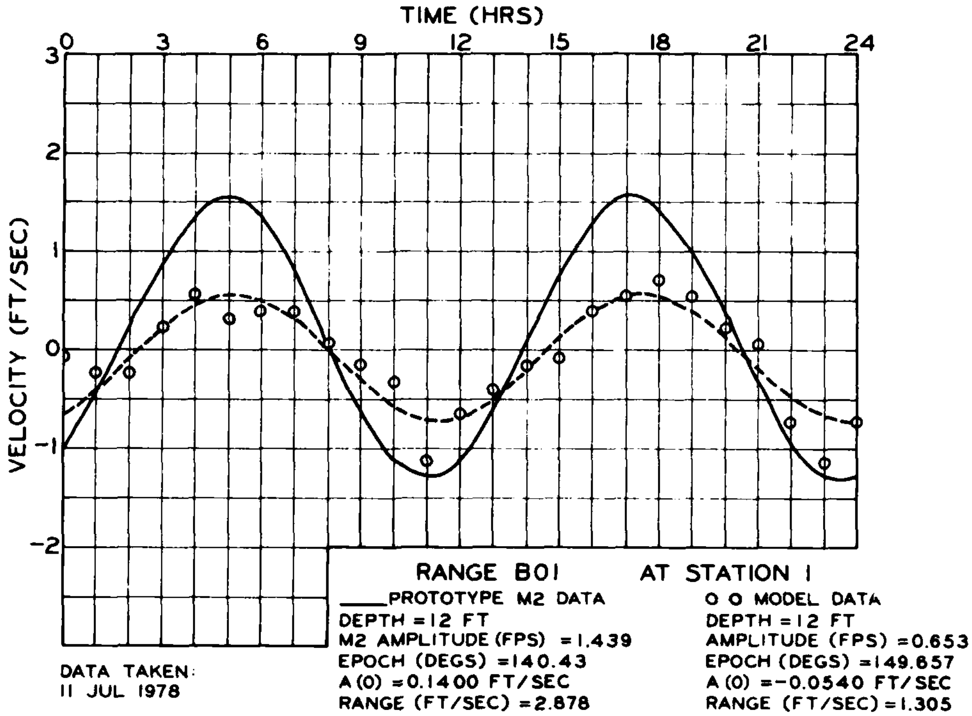




Plate C72. Model/prototype velocity comparison,
Range P05, sta 2 and Range P06, sta 1



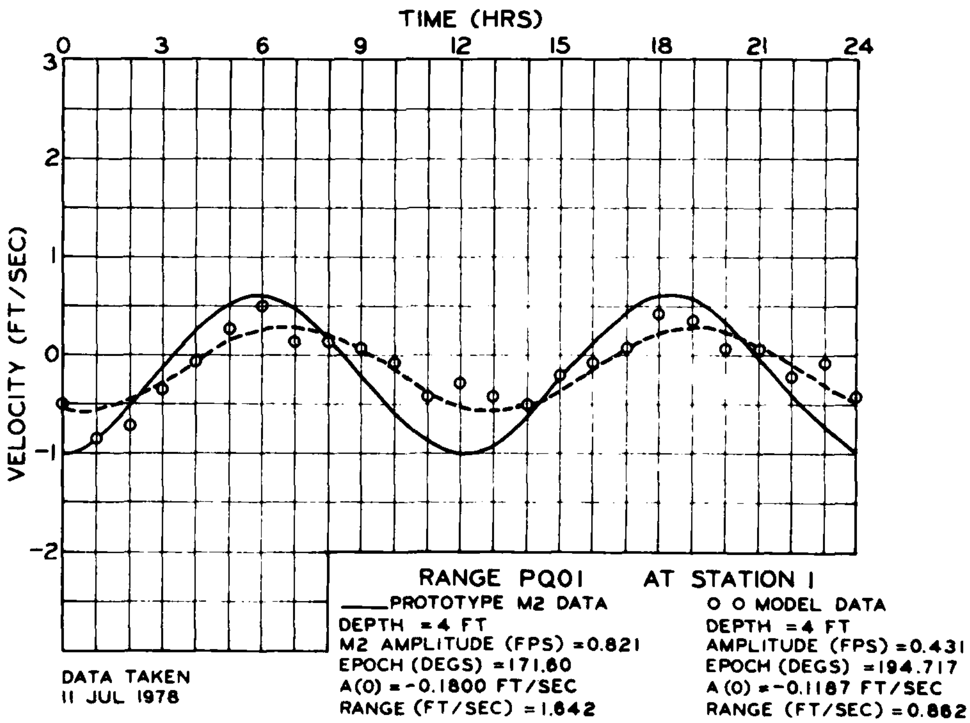
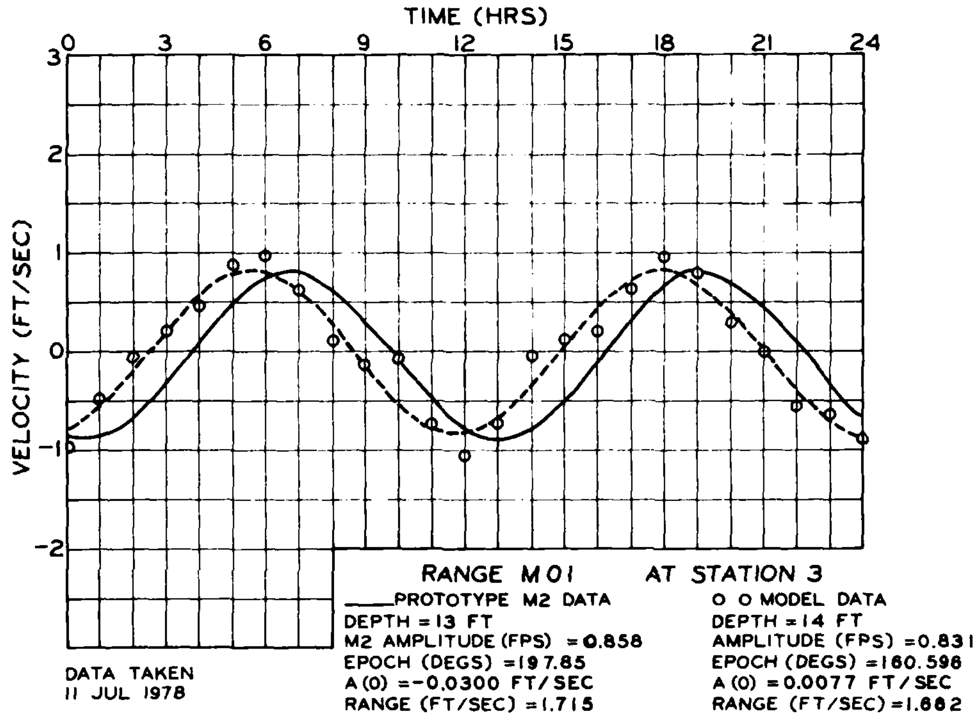




Plate C73. Model/prototype velocity comparison, Range B01, sta 1 and Range PQ01, sta 1



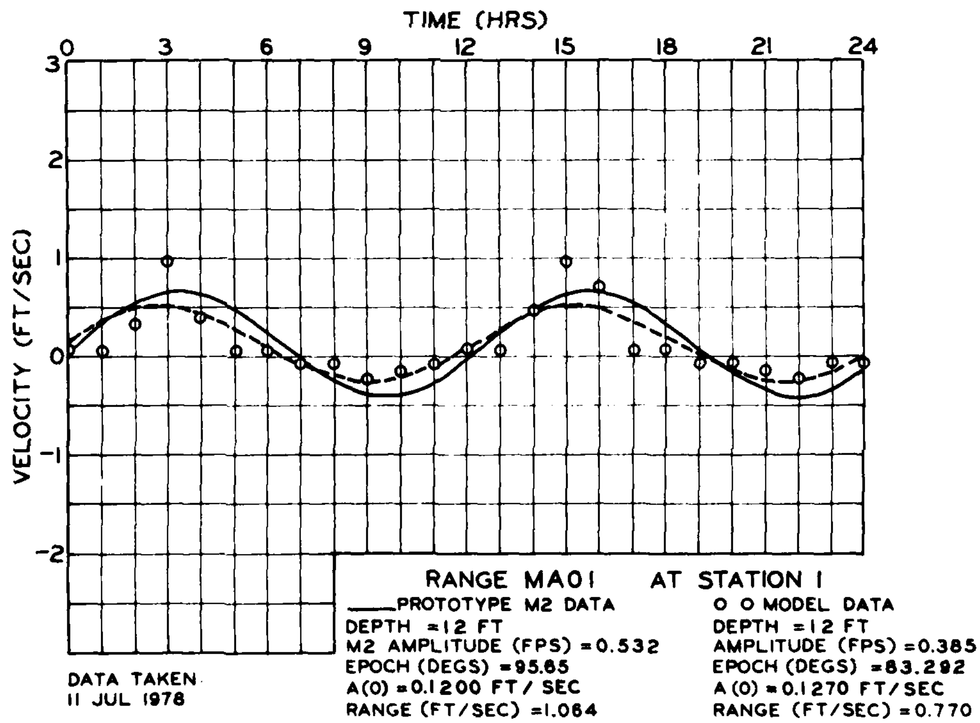
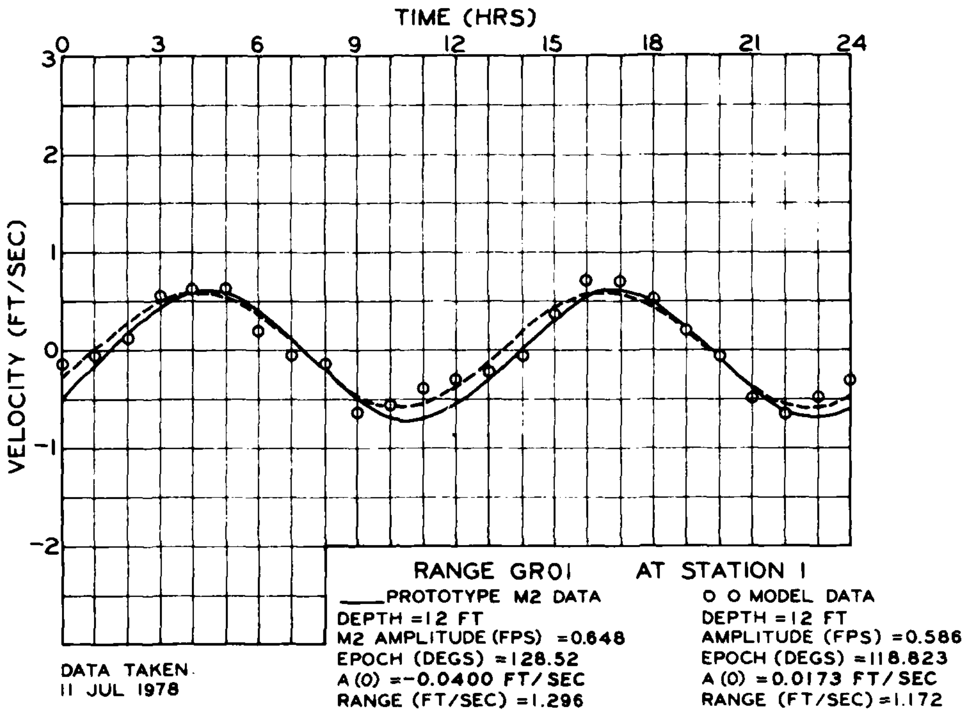




Plate C74. Model/prototype velocity comparison, Range M01, sta 3 and Range MA01, sta 1



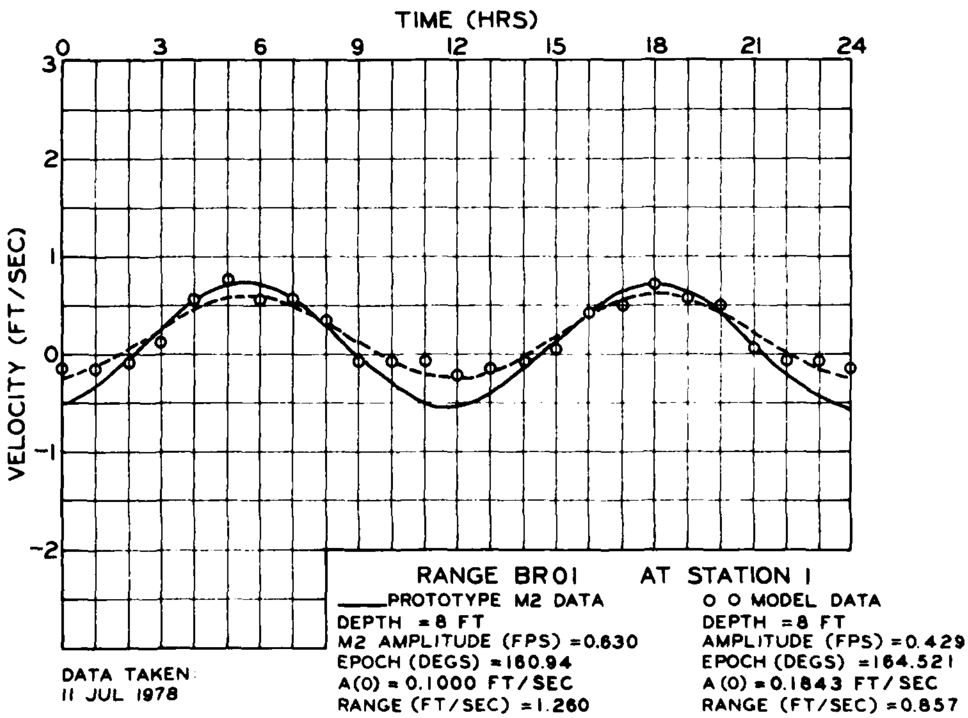
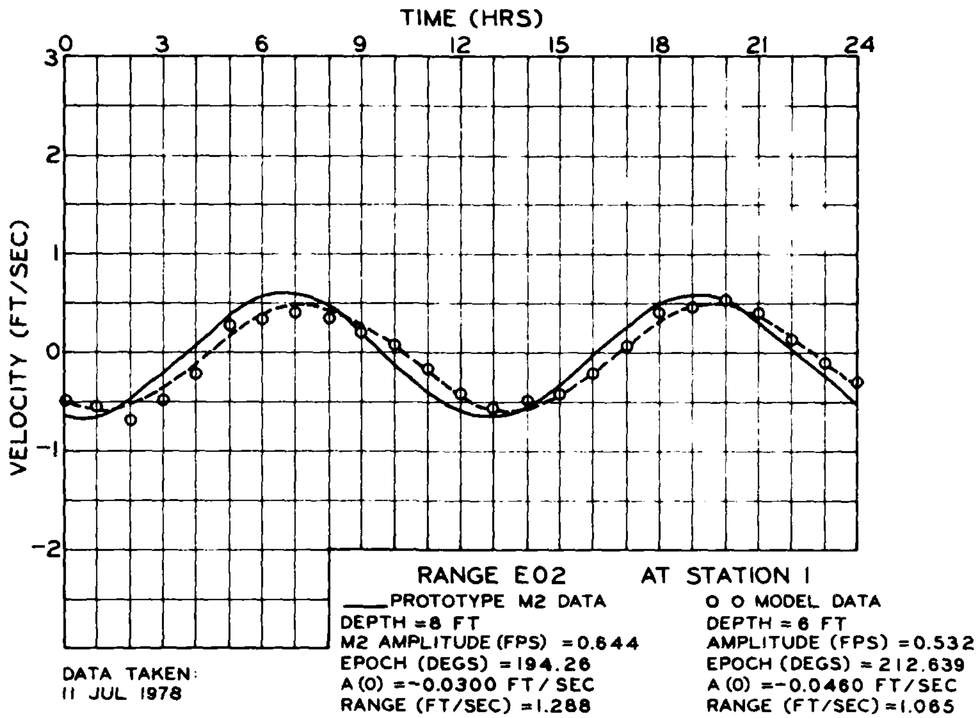




Plate C75. Model/prototype velocity comparison, Range GR01, sta 1 and Range BR01, sta 1



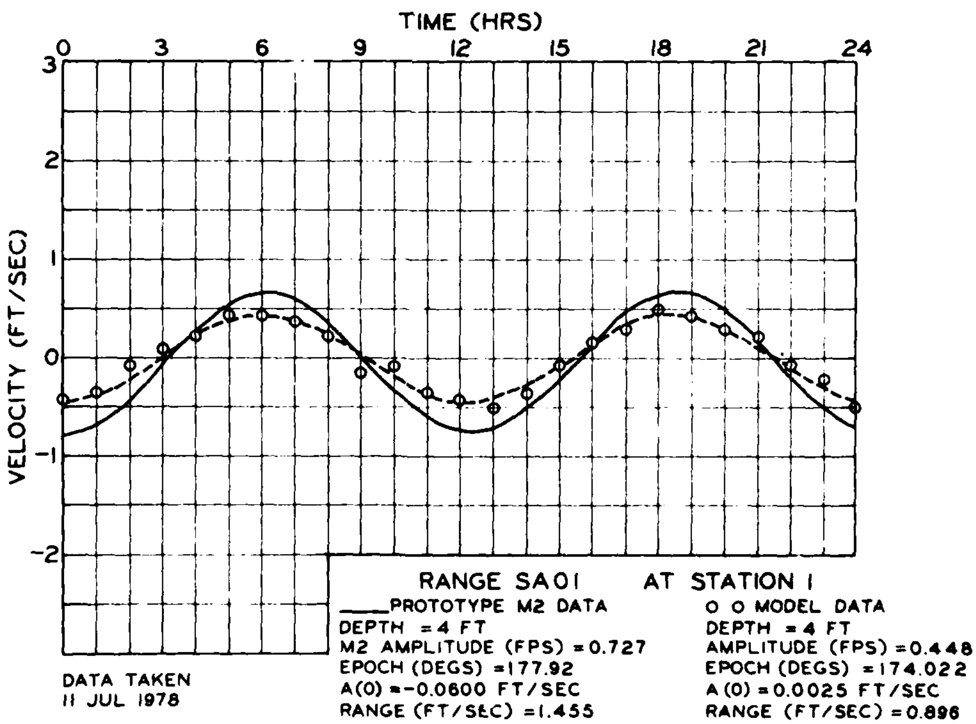
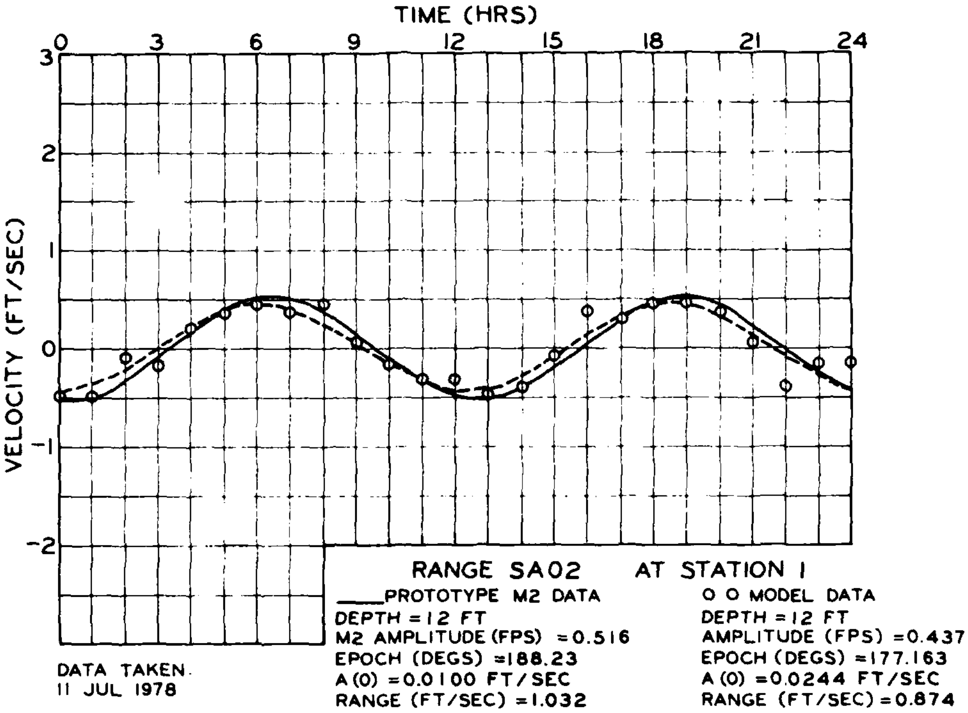




Plate .76. Model/prototype velocity comparison,
Range E02, sta 1 and Range SA01, sta 1



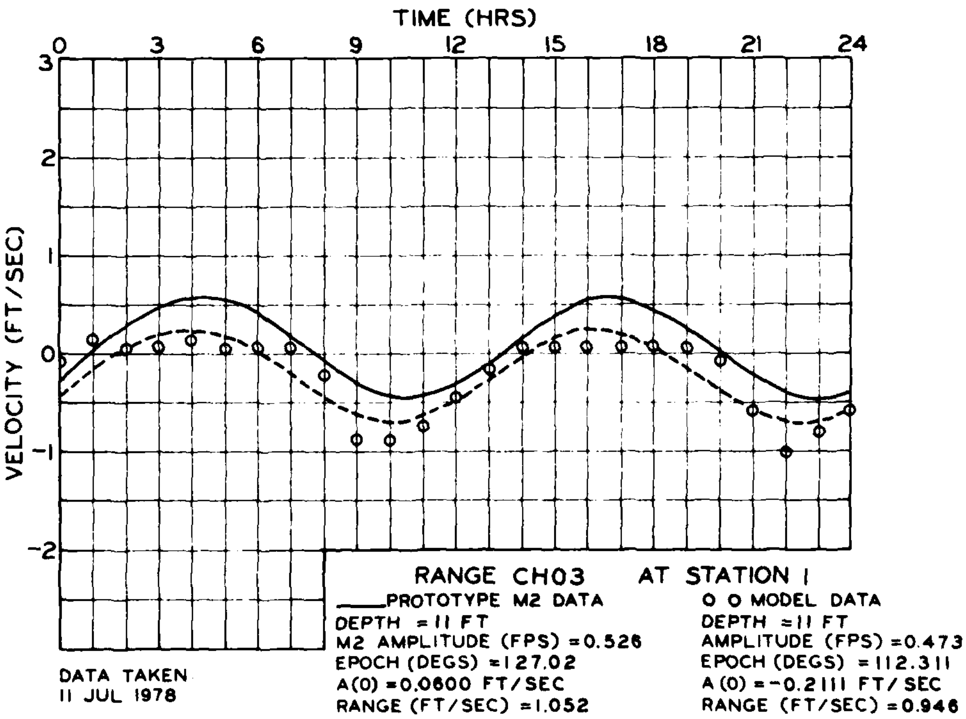
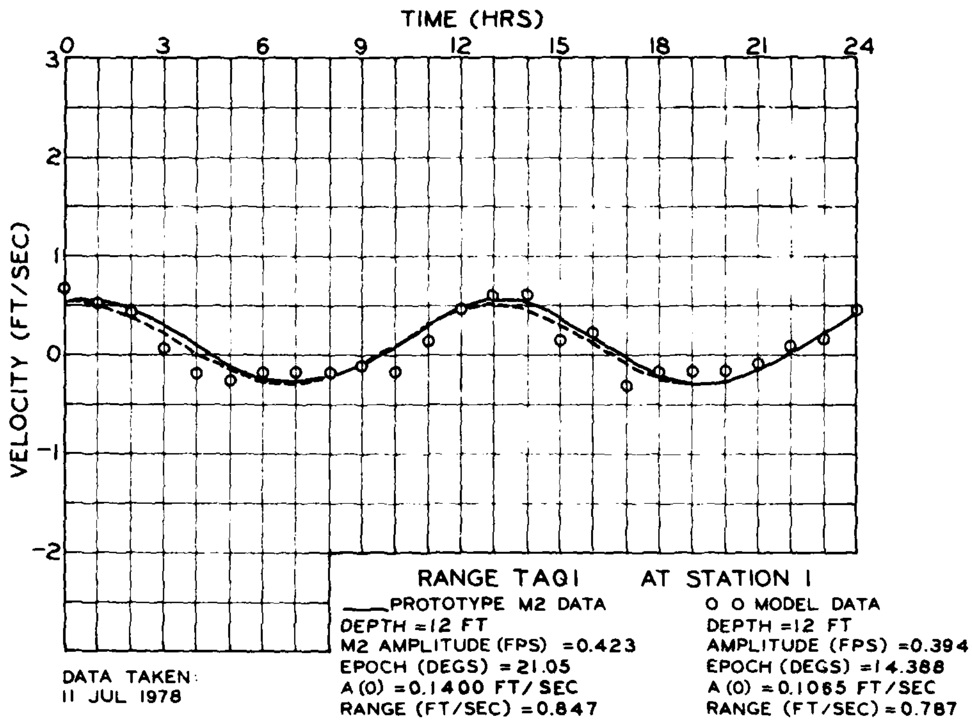




Plate C77. Model/prototype velocity comparison, Range SA02, sta 1 and Range CH03, sta 1



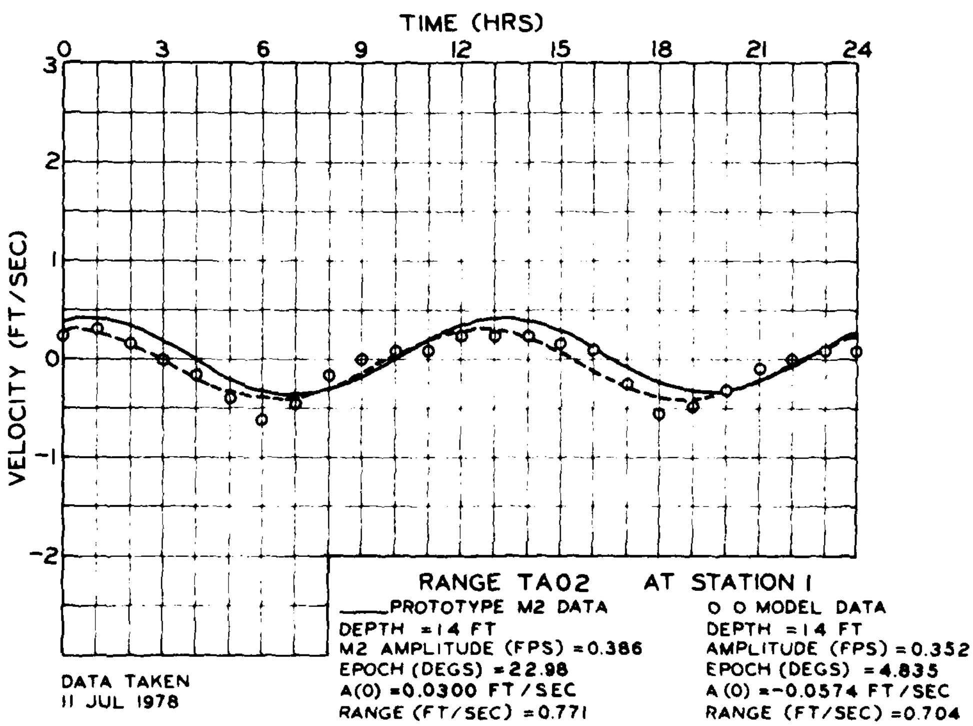
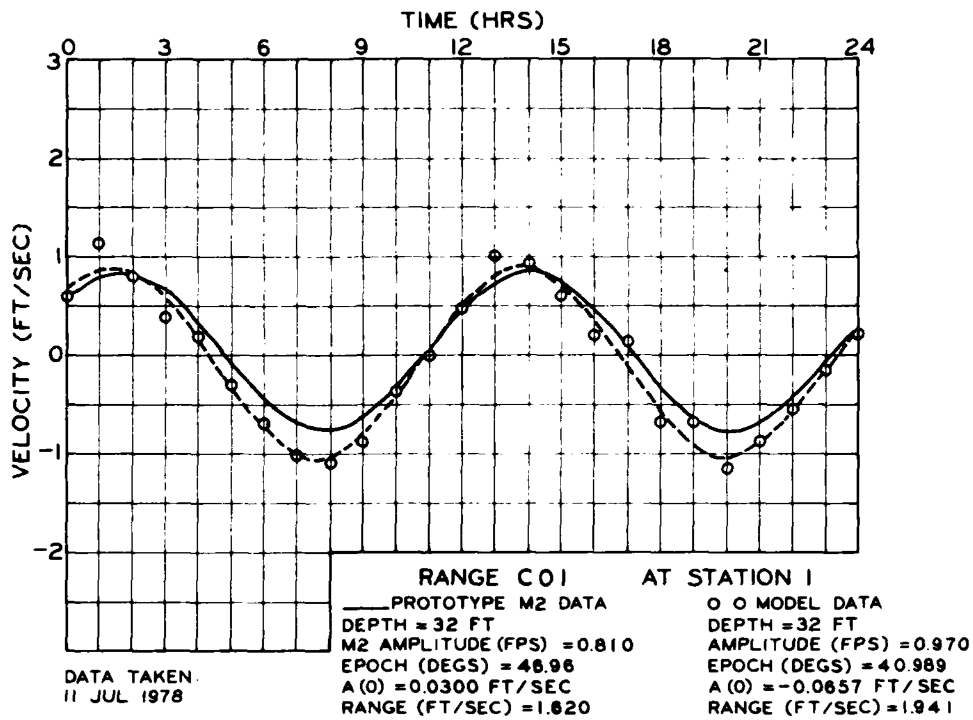




Plate C78. Model/prototype velocity comparison, Range TA01, sta 1 and Range TA02, sta 1



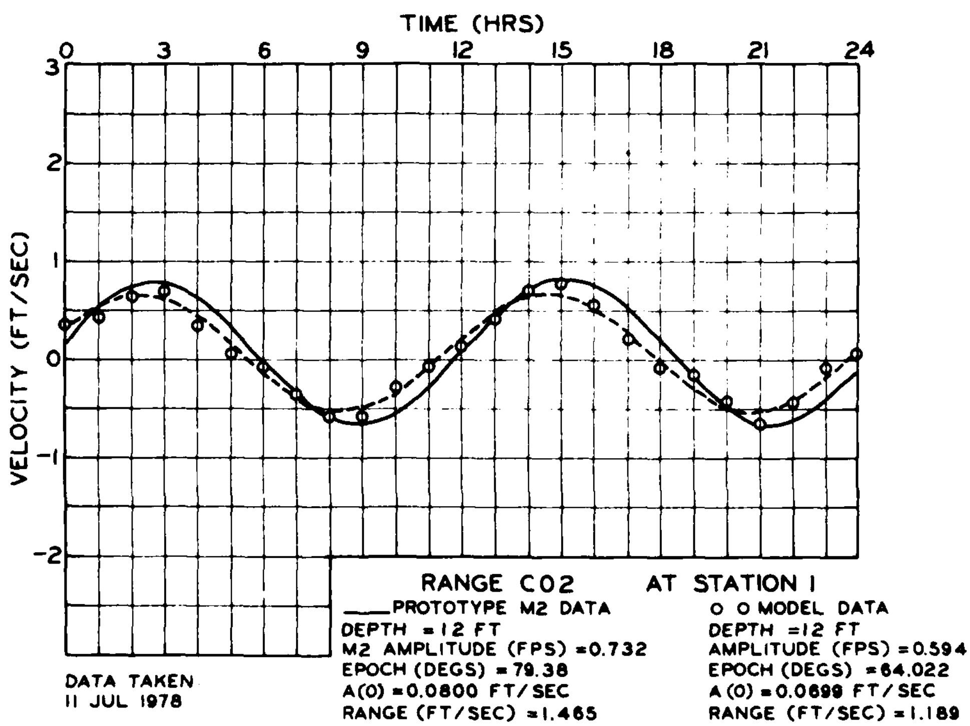
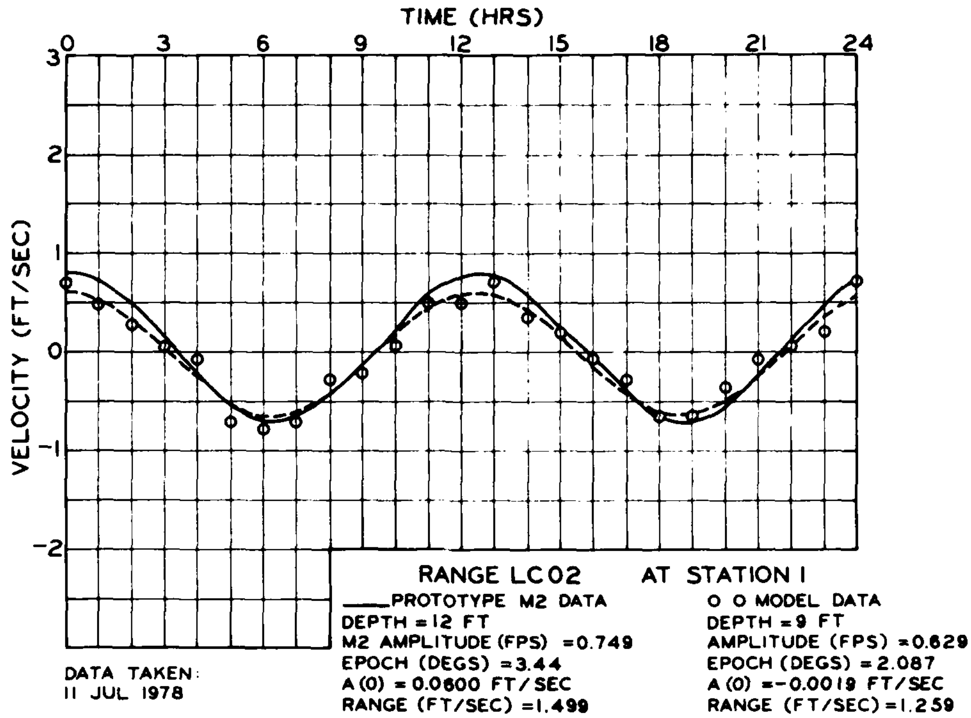




Plate C79. Model/prototype velocity comparison, Range C01, sta 1 and Range C02, sta 1



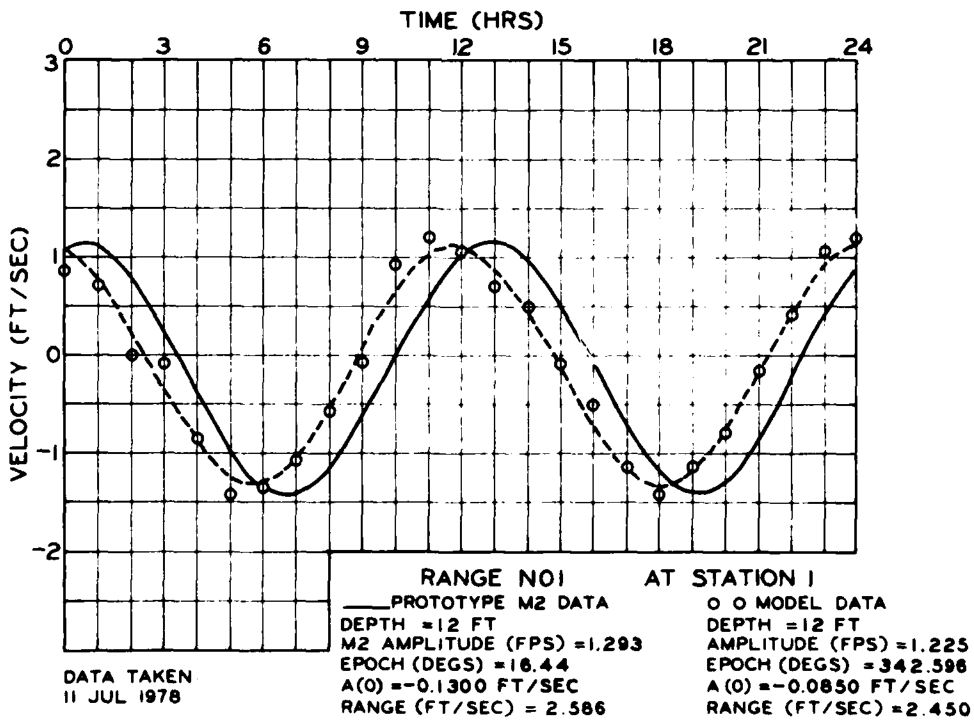
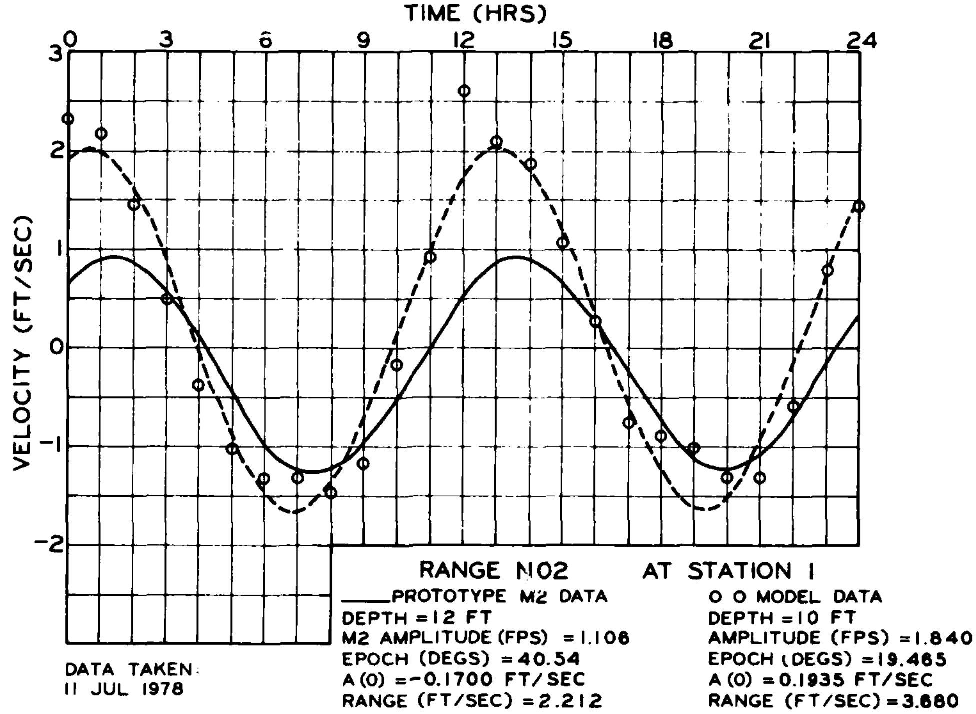




Plate C80. Model/prototype velocity comparison, Range LC02, sta 1 and Range N01, sta 1



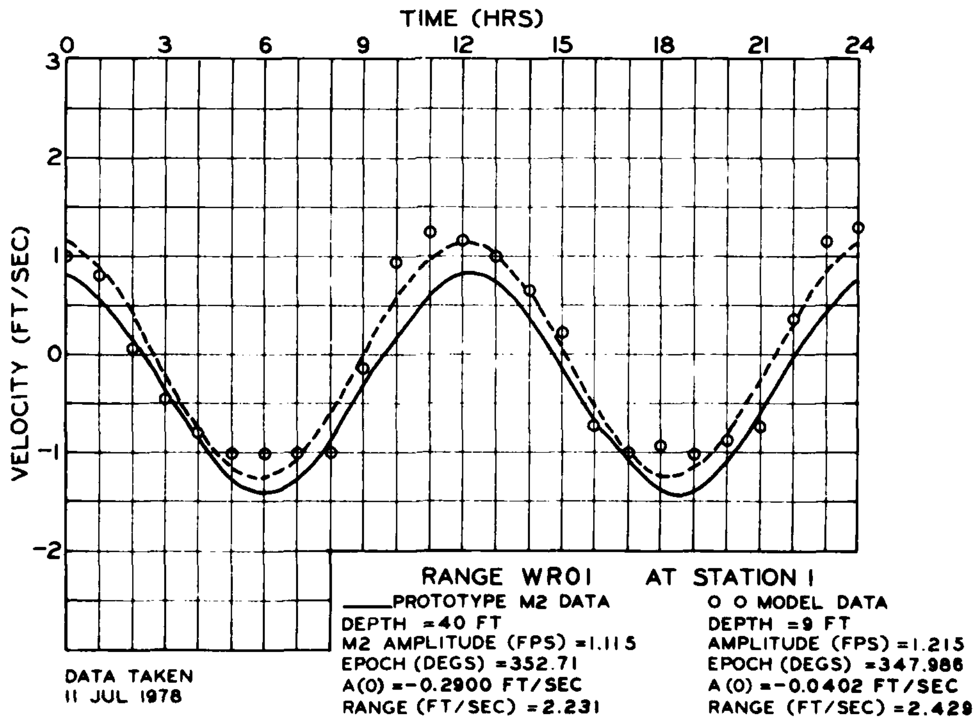




Plate C81. Model/prototype velocity comparison,
Range NO2, sta 1 and Range WR01, sta 1

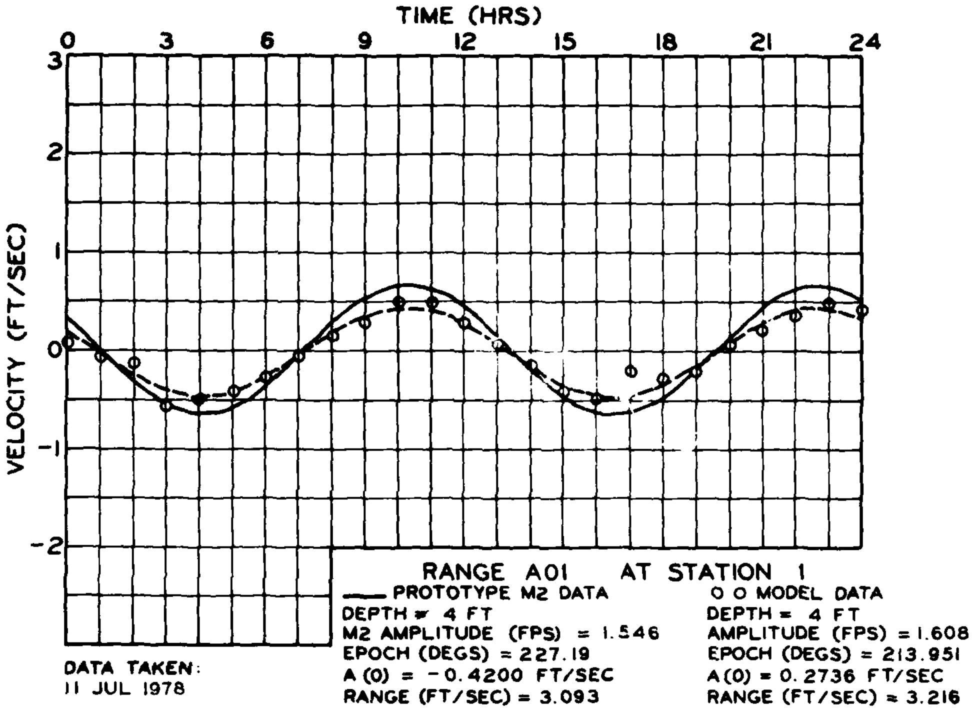



Plate C82. Model/prototype velocity comparison, Range A01, sta 1

APPENDIX D

SALINITY VERIFICATION DATA

Boundary Control Inflow Hydrographs and Comparisons of
Model and Prototype Salinity Distributions for
Selected Salinity Stations

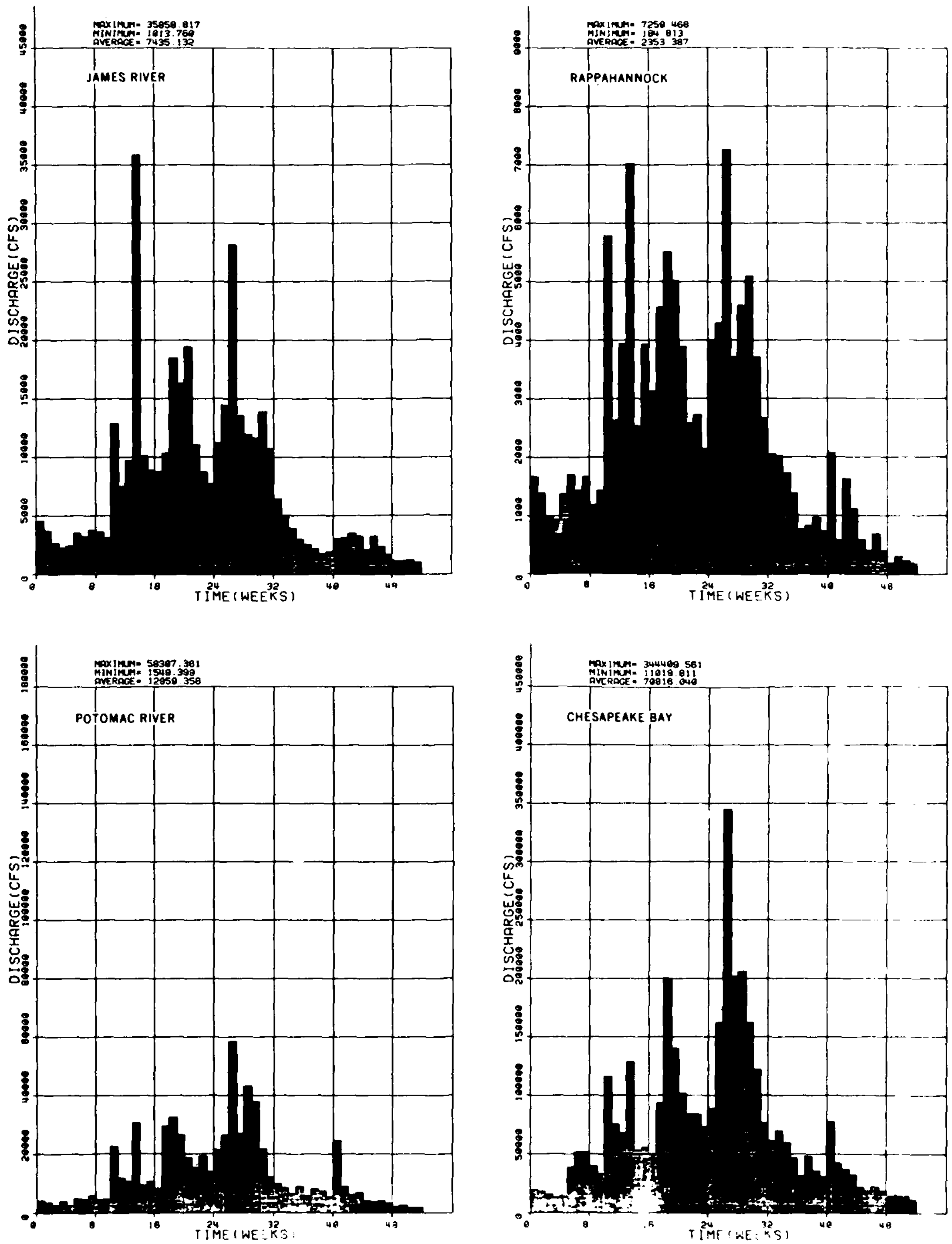



Plate D1. Freshwater inflow hydrographs, 1 Oct 1969-30 Sep 1970

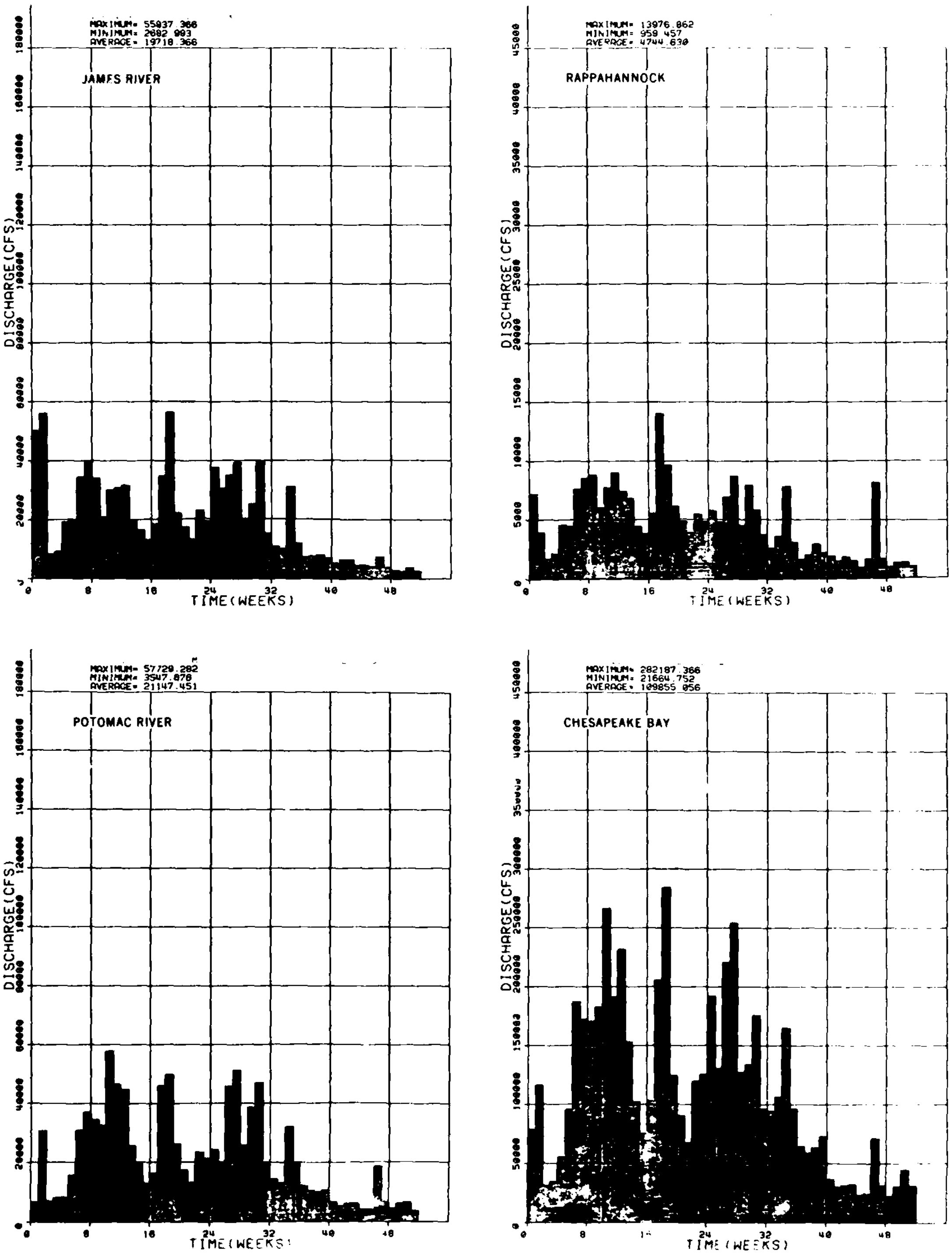



Plate D2. Freshwater inflow hydrographs, 1 Oct 1970-30 Sep 1971

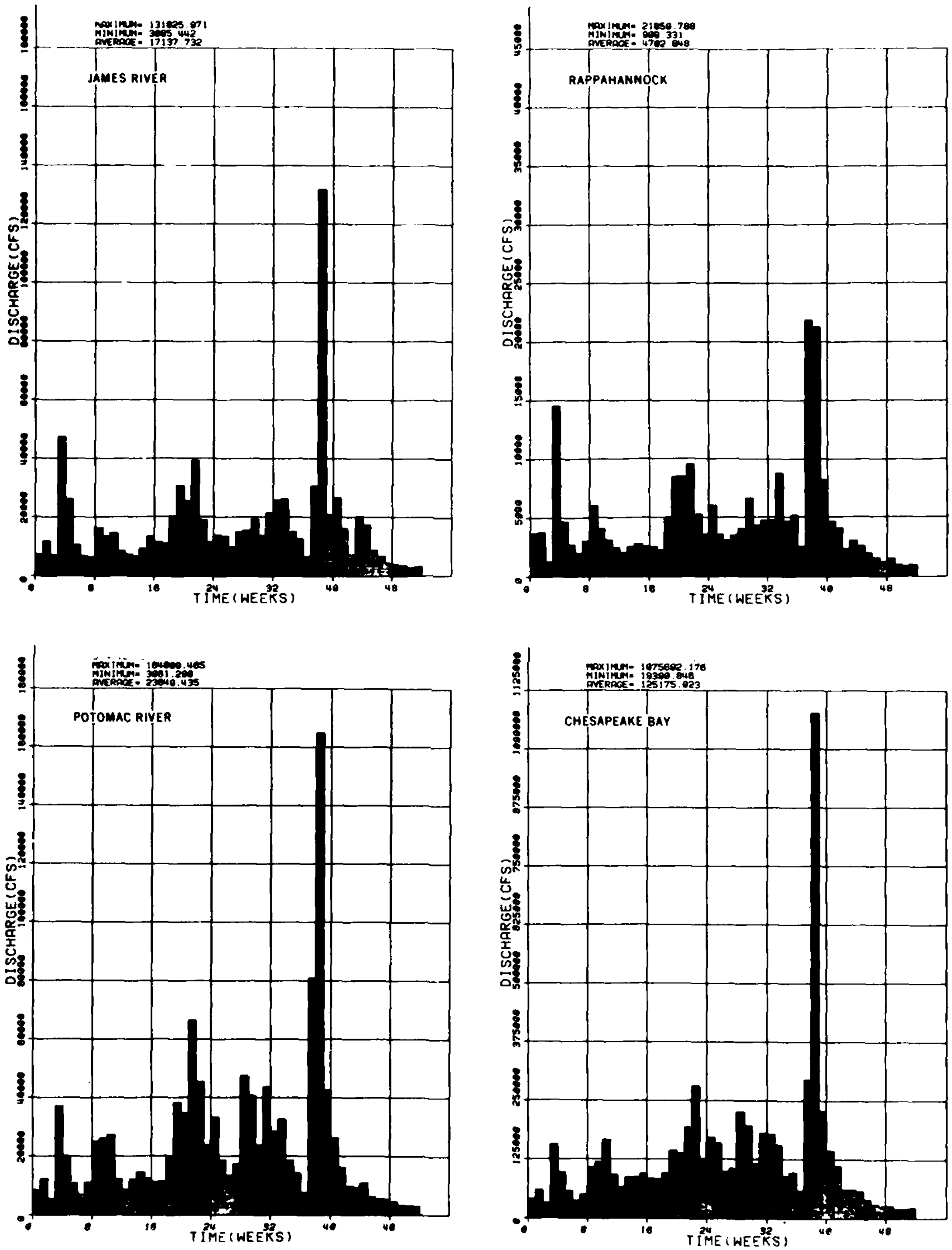



Plate D3. Freshwater inflow hydrographs, 1 Oct 1981-30 Sep 1972

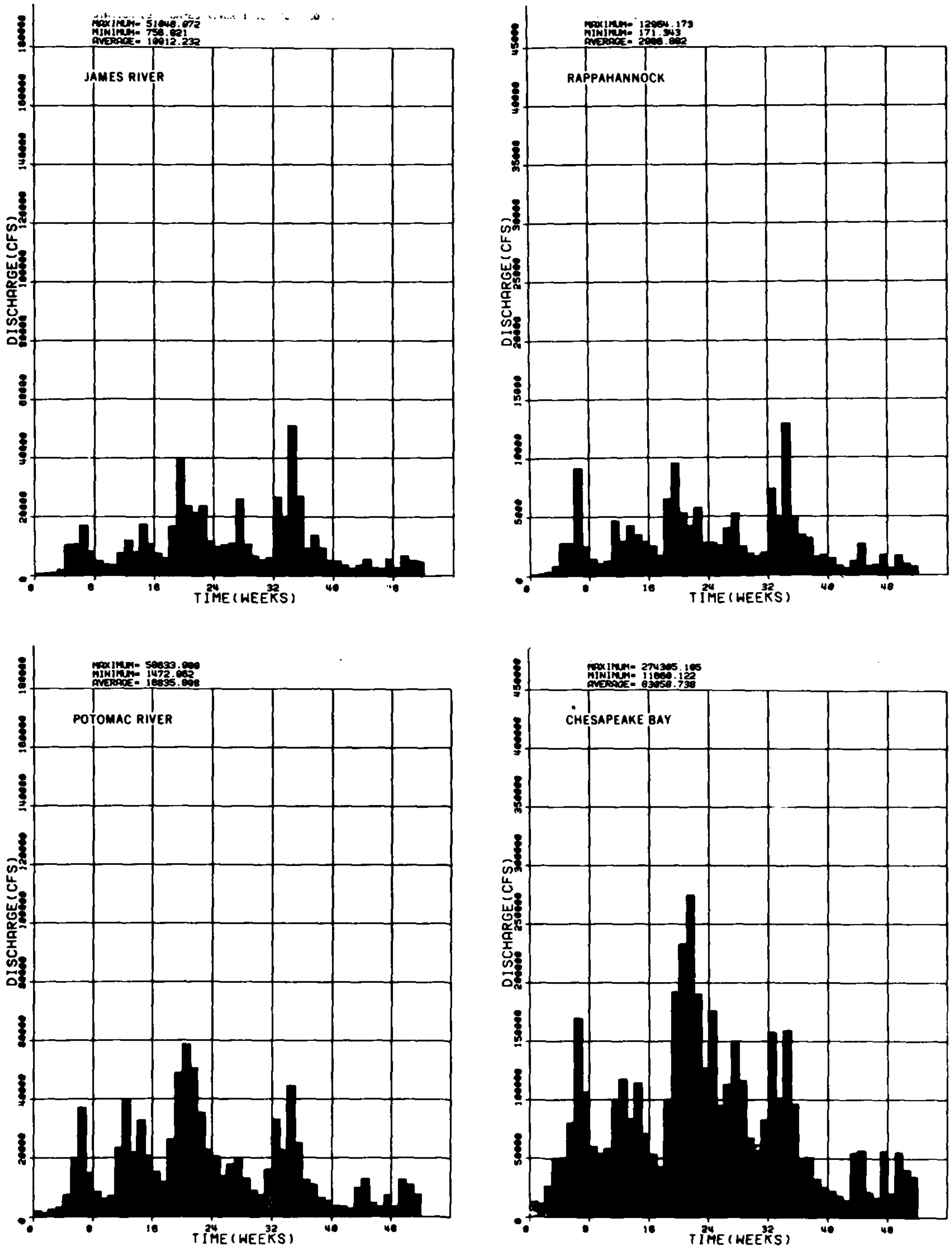



Plate D4. Freshwater inflow hydrographs, 1 Oct 1972-30 Sep 1973

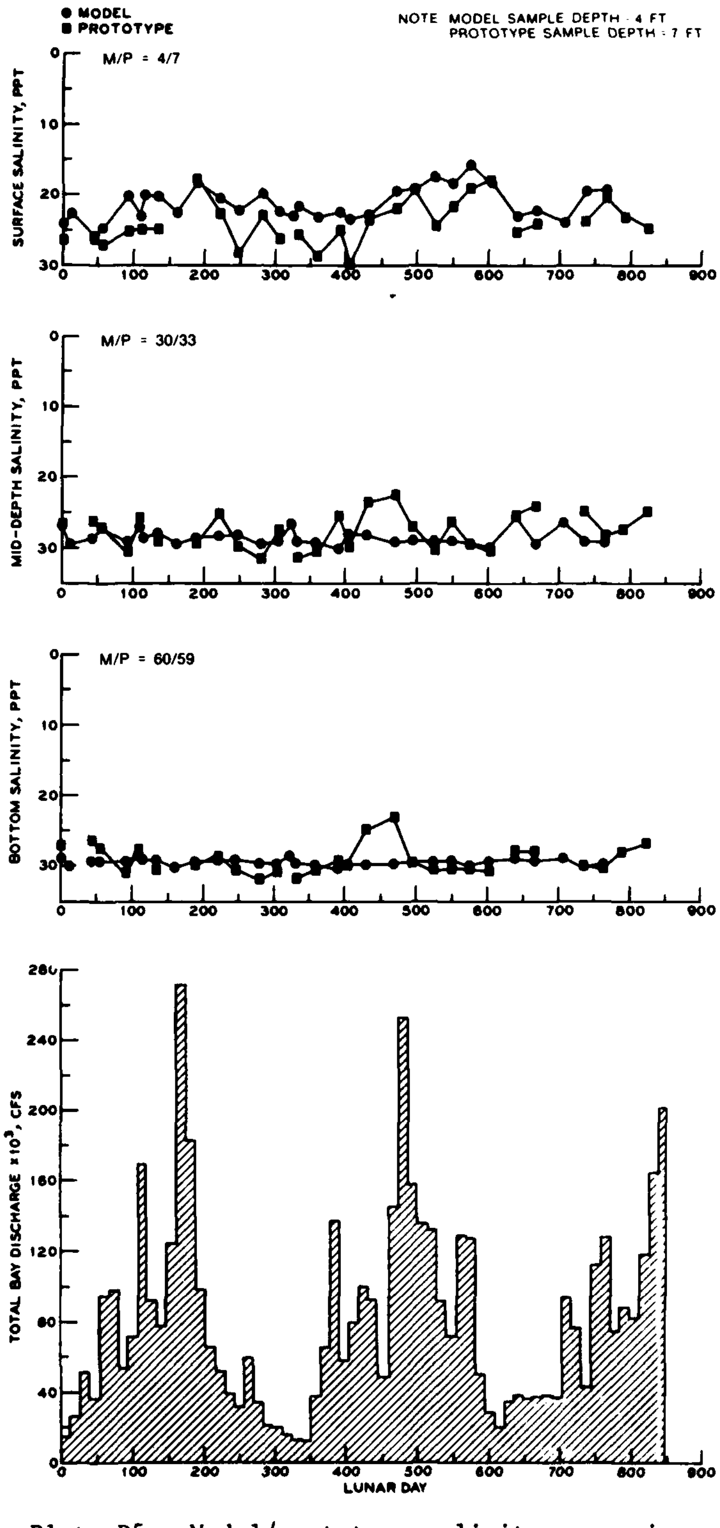



Plate D5. Model/prototype salinity comparison, sta A, Hydrograph IV

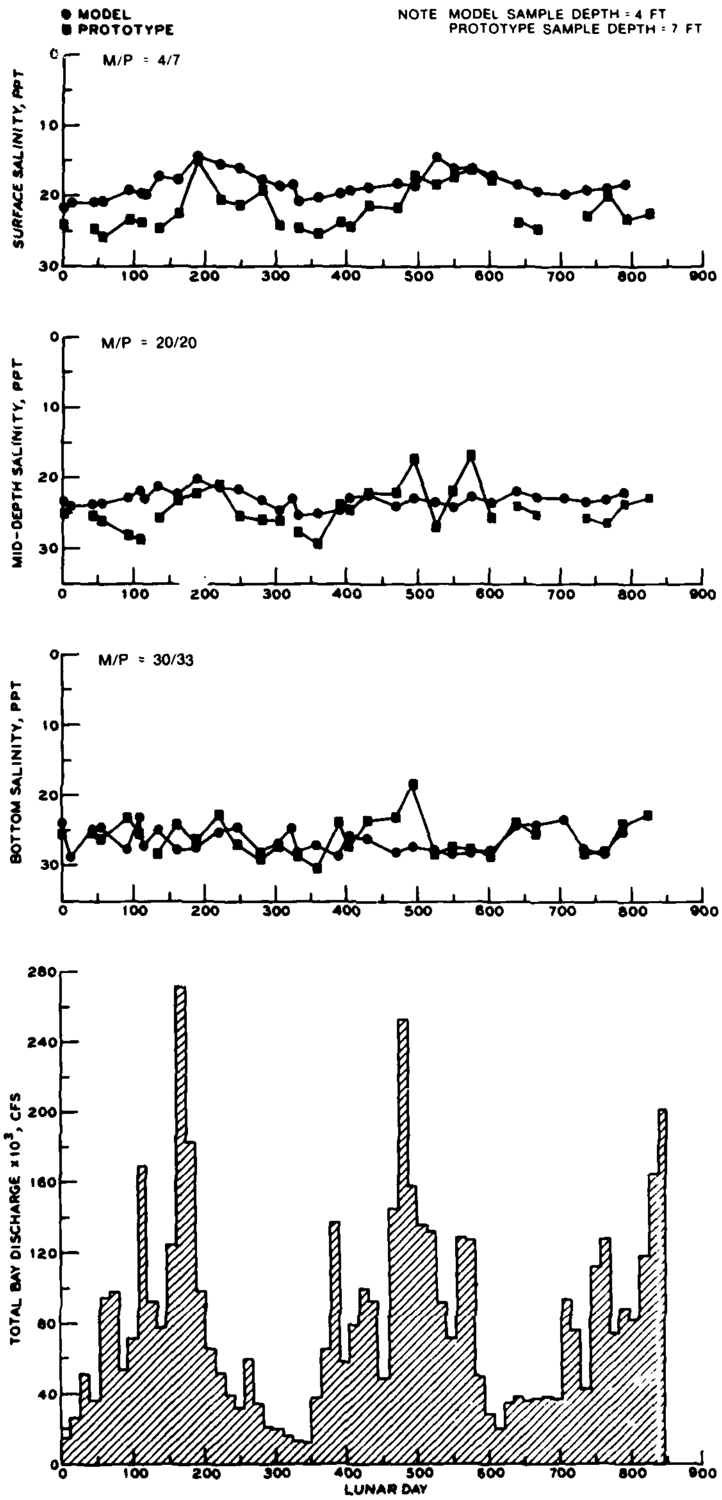



Plate D6. Model/prototype salinity comparison, sta B, Hydrograph IV

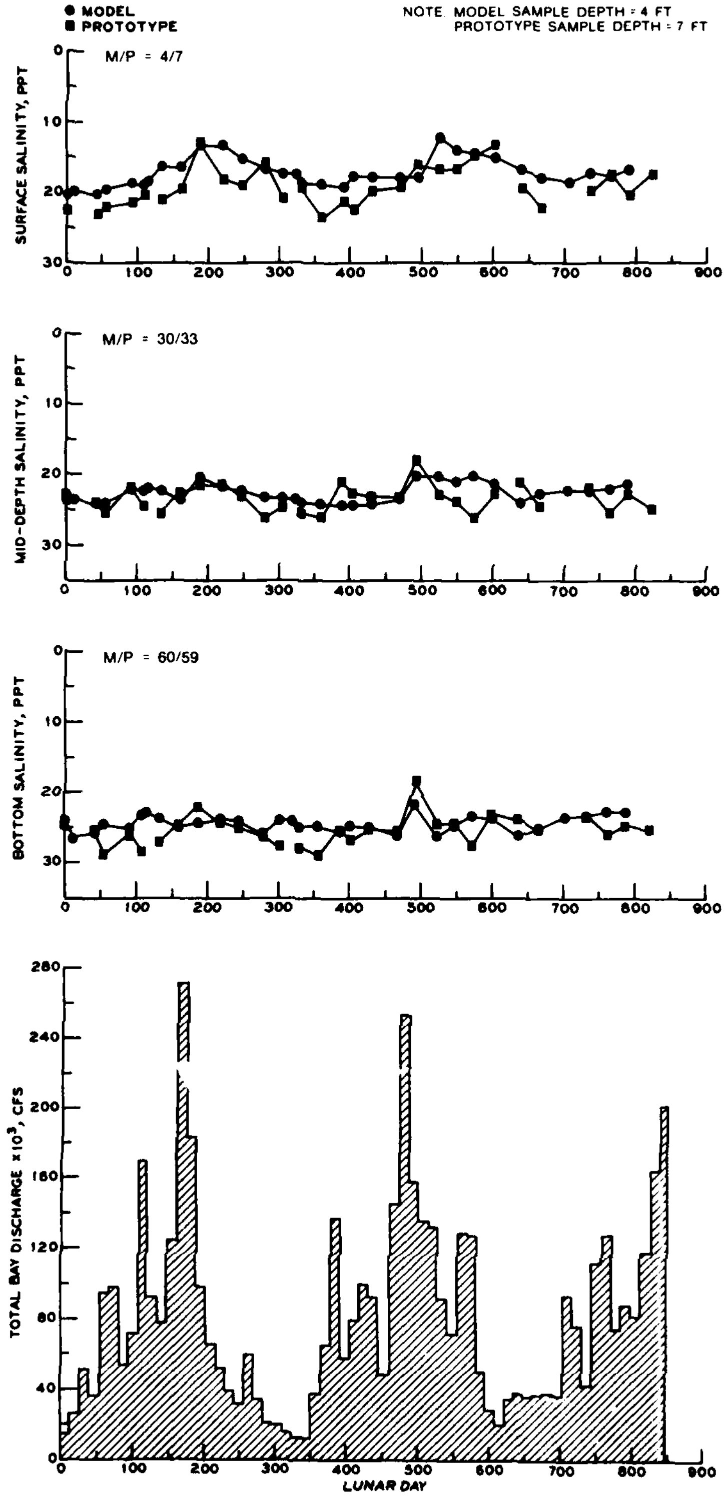



Plate D7. Model/prototype salinity comparison, sta C, Hydrograph IV

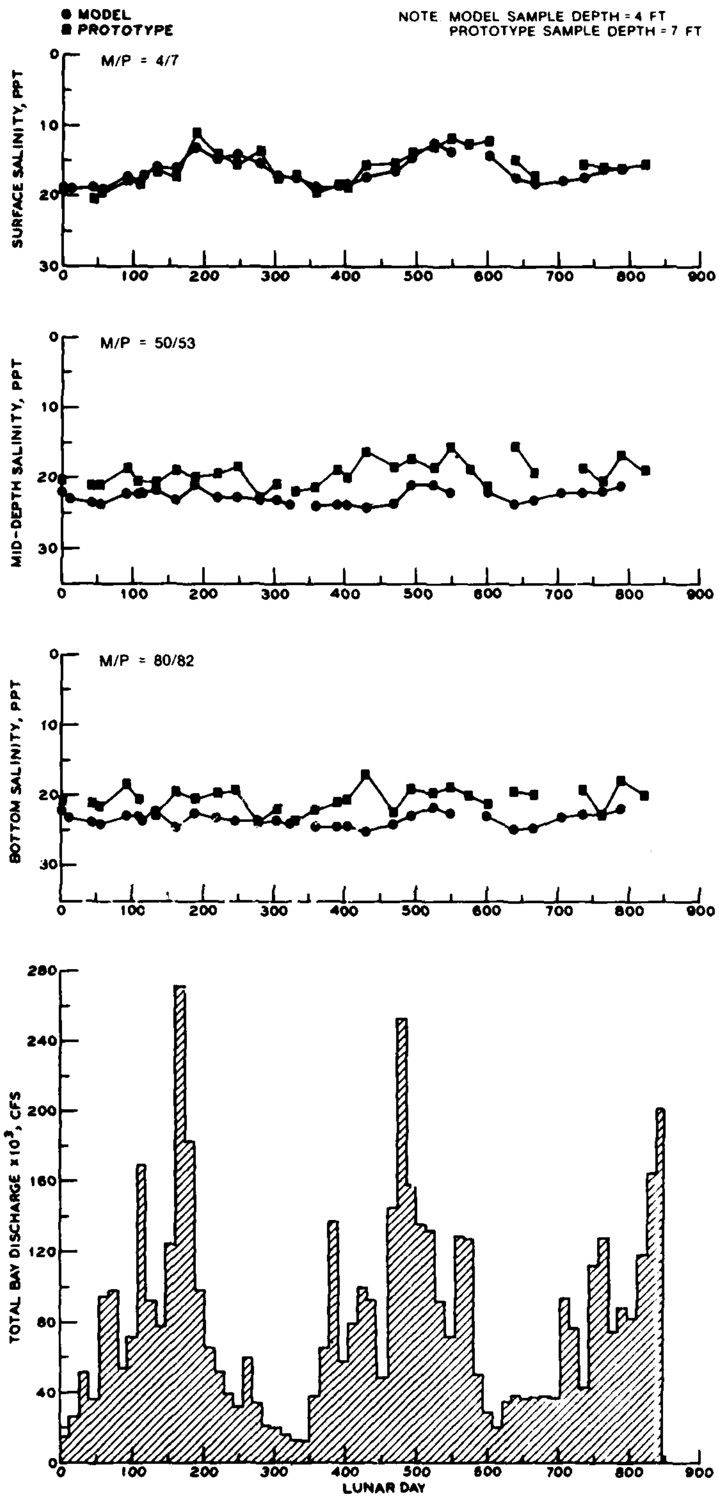



Plate D8. Model/prototype salinity comparison, sta D, Hydrograph IV

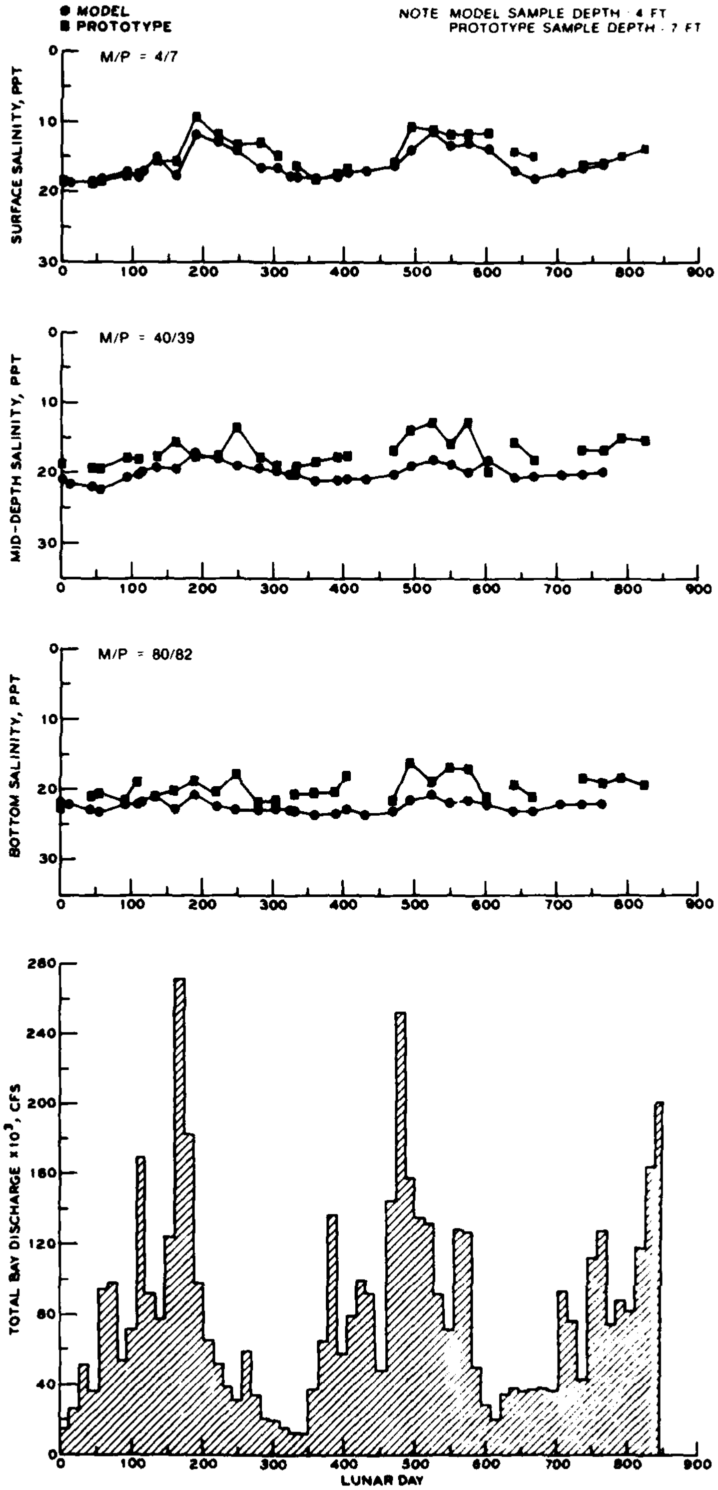



Plate D9. Model/prototype salinity comparison, sta E, Hydrograph IV

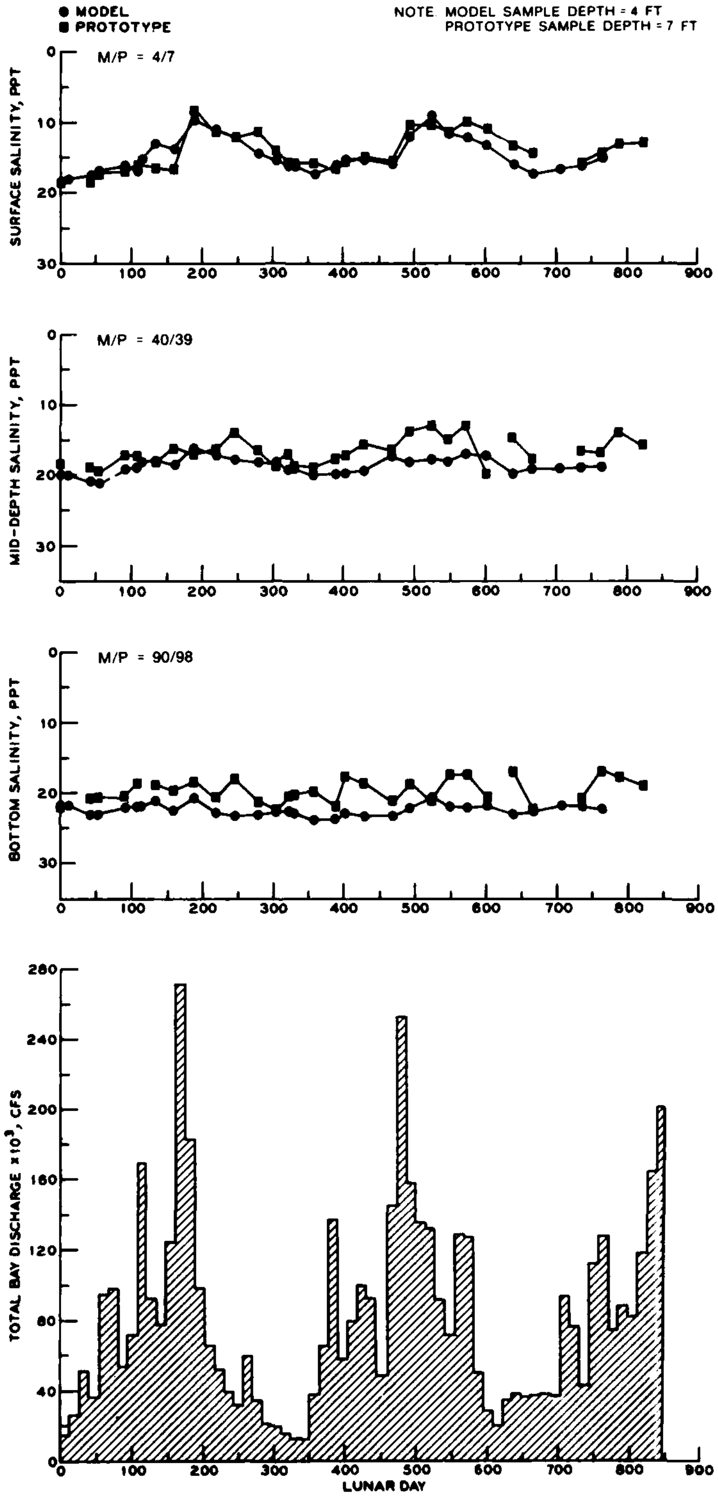



Plate D10. Model/prototype salinity comparison, sta F, Hydrograph IV

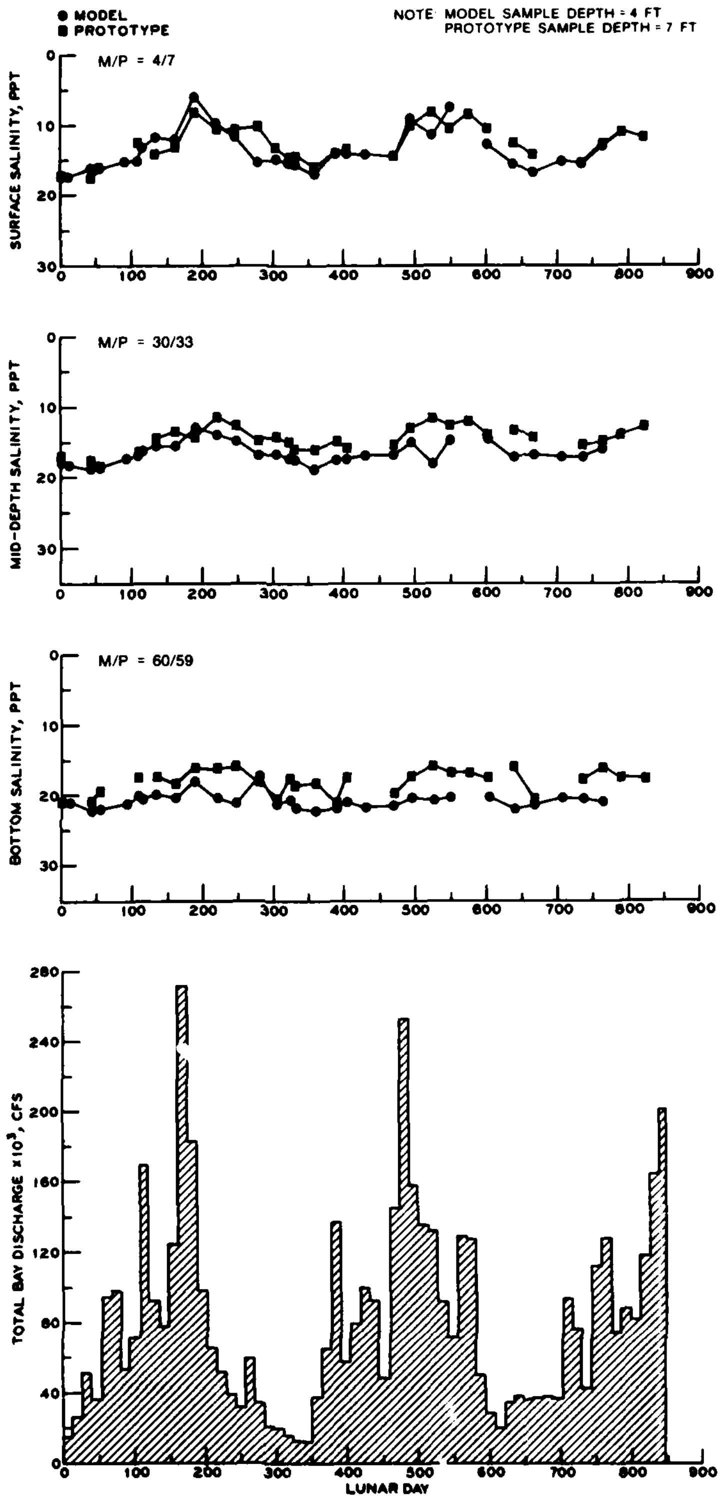



Plate D11. Model/prototype salinity comparison, sta G, Hydrograph IV

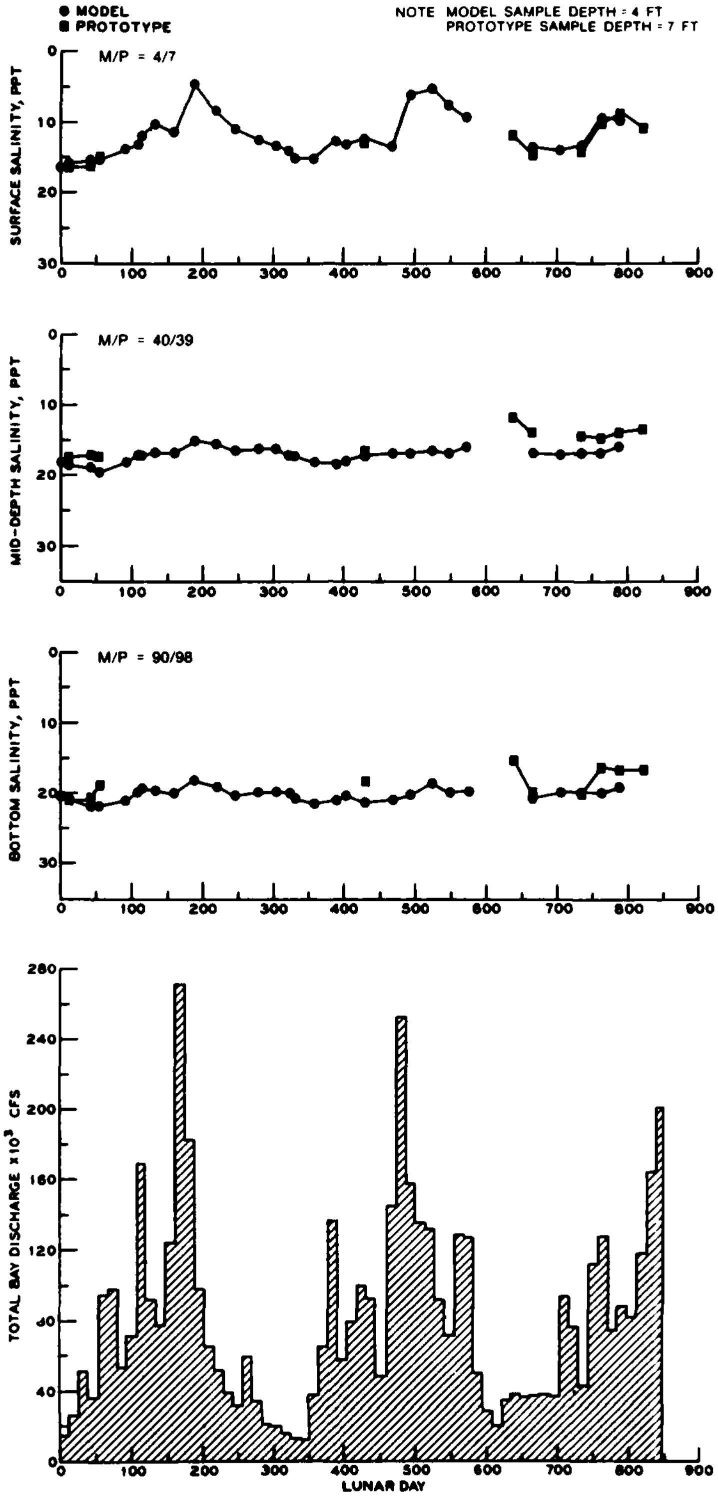



Plate D12. Model/prototype salinity comparison, sta H, Hydrograph IV

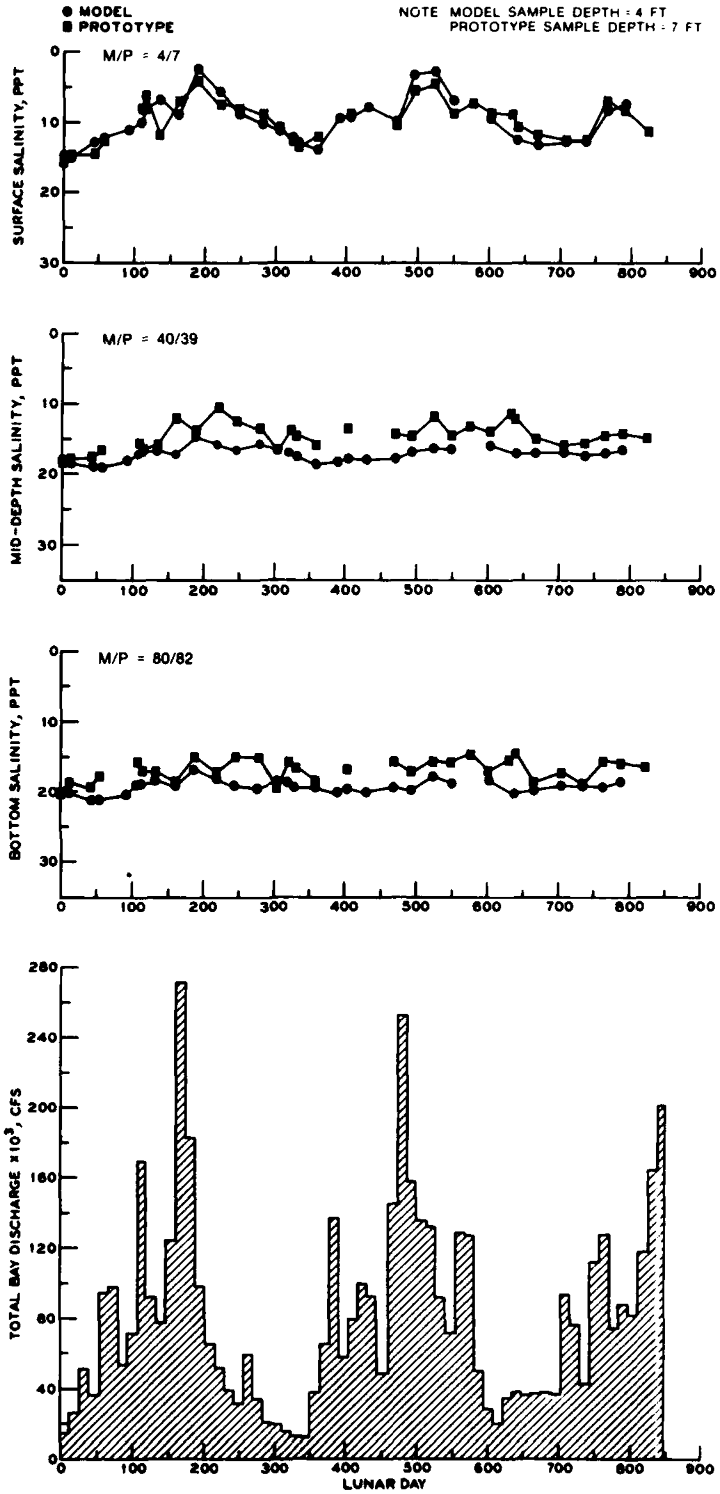



Plate D13. Model/prototype salinity comparisons, sta I, Hydrograph IV

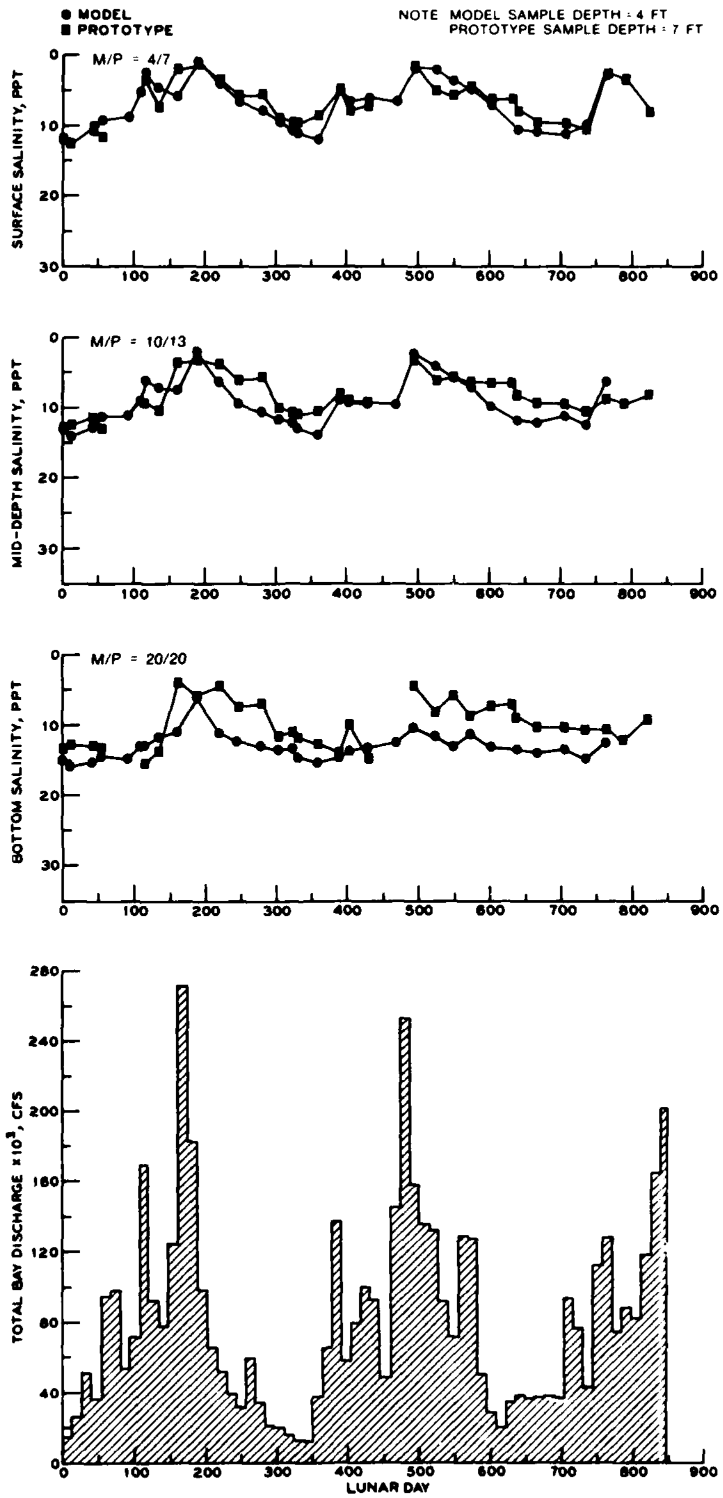



Plate D14. Model/prototype salinity comparison, sta J, Hydrograph IV

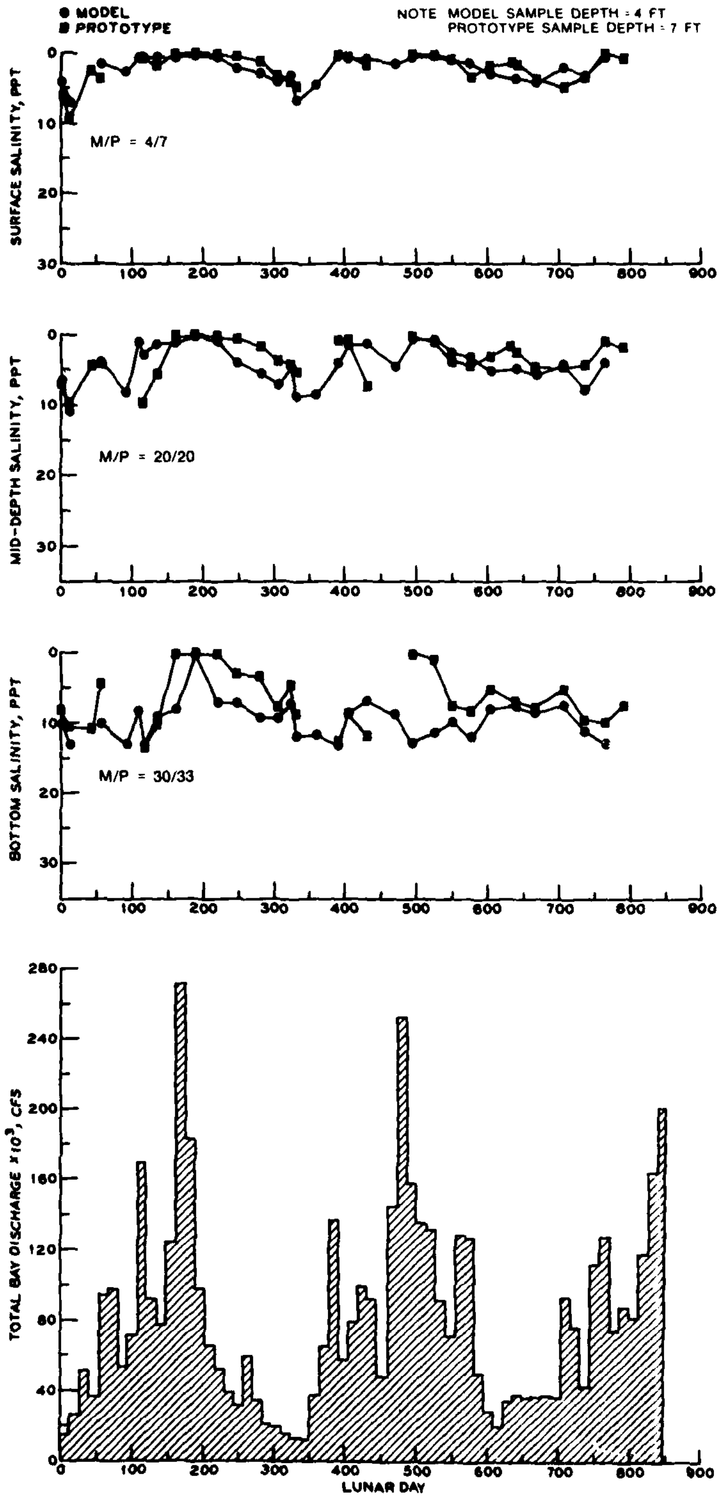



Plate D15. Model/prototype salinity comparison, sta K, Hydrograph IV

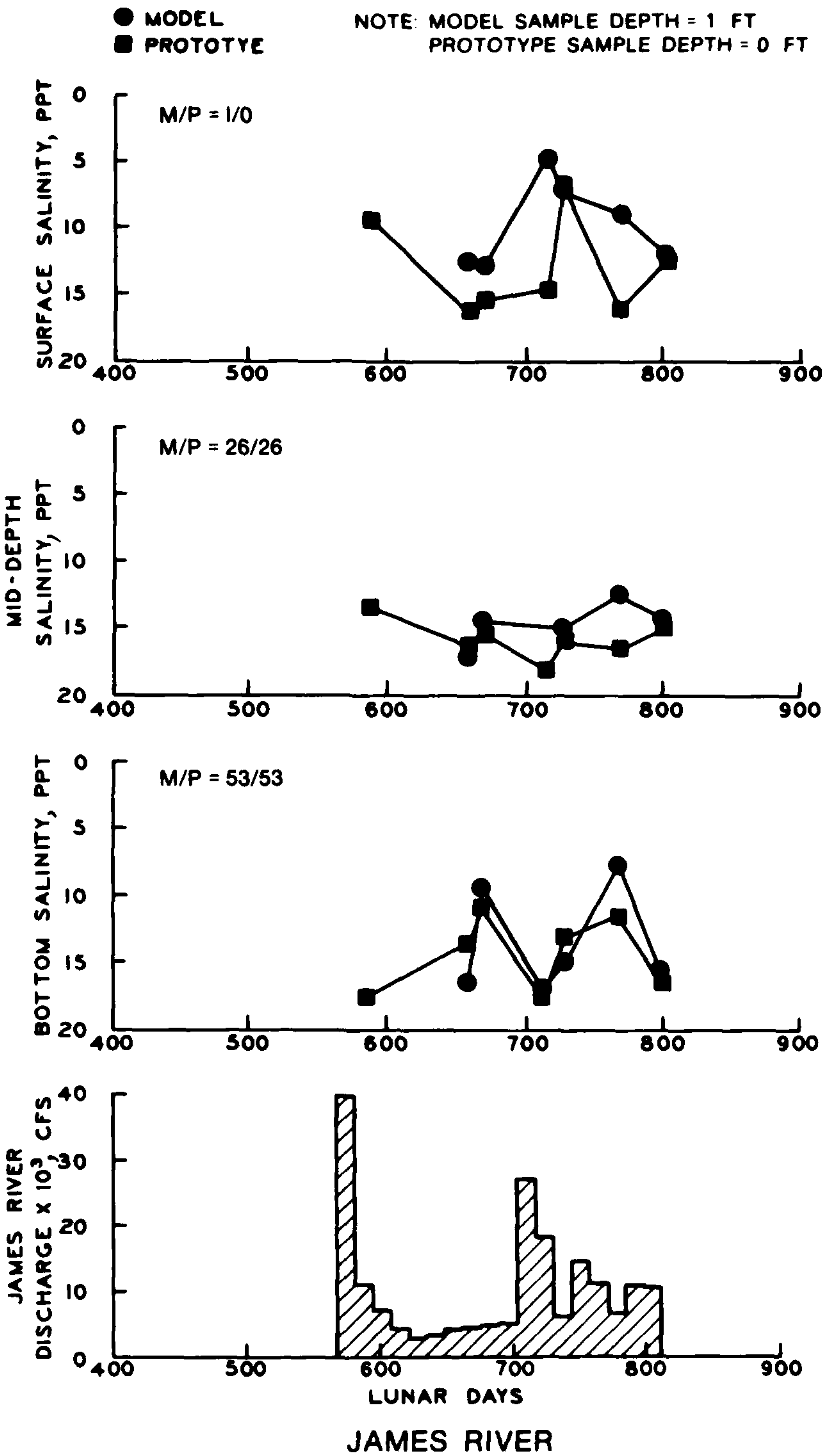



Plate D16. Model/prototype salinity comparison, sta $J_1$, Hydrograph IV

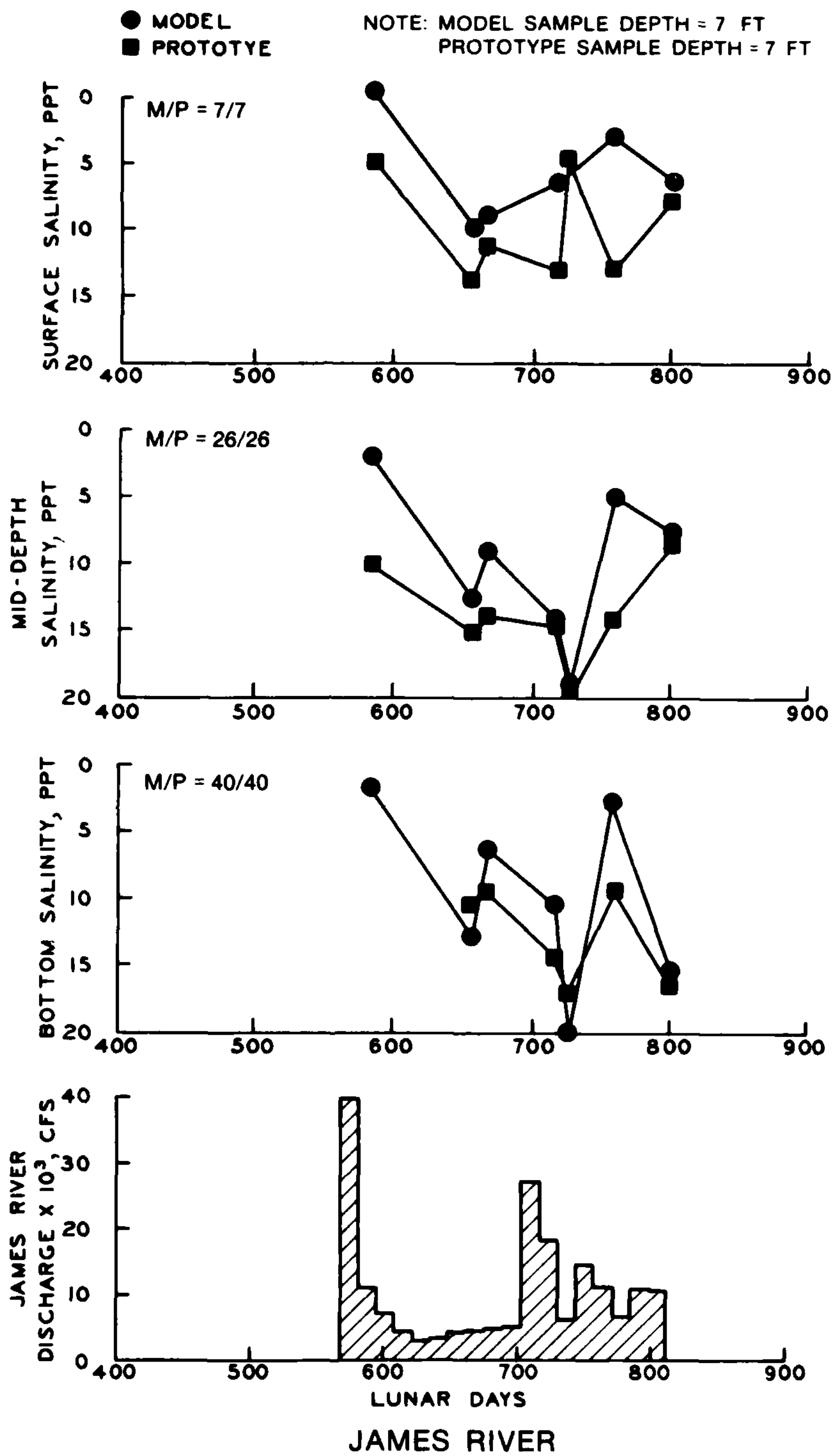



Plate D17. Model/prototype salinity comparison, sta $J_2$, Hydrograph IV

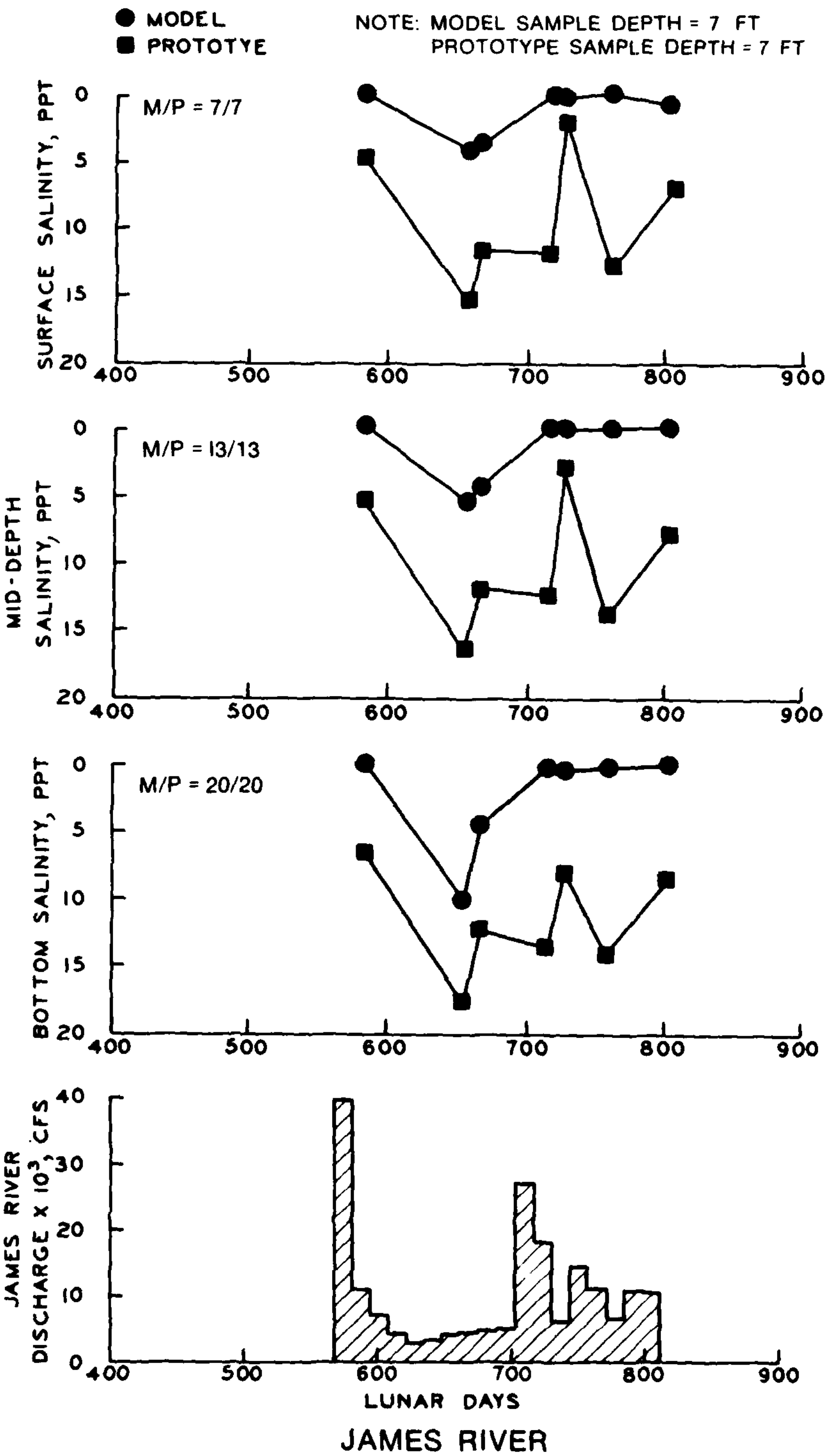



Plate D18. Model/prototype salinity comparison, sta $J_3$, Hydrograph IV

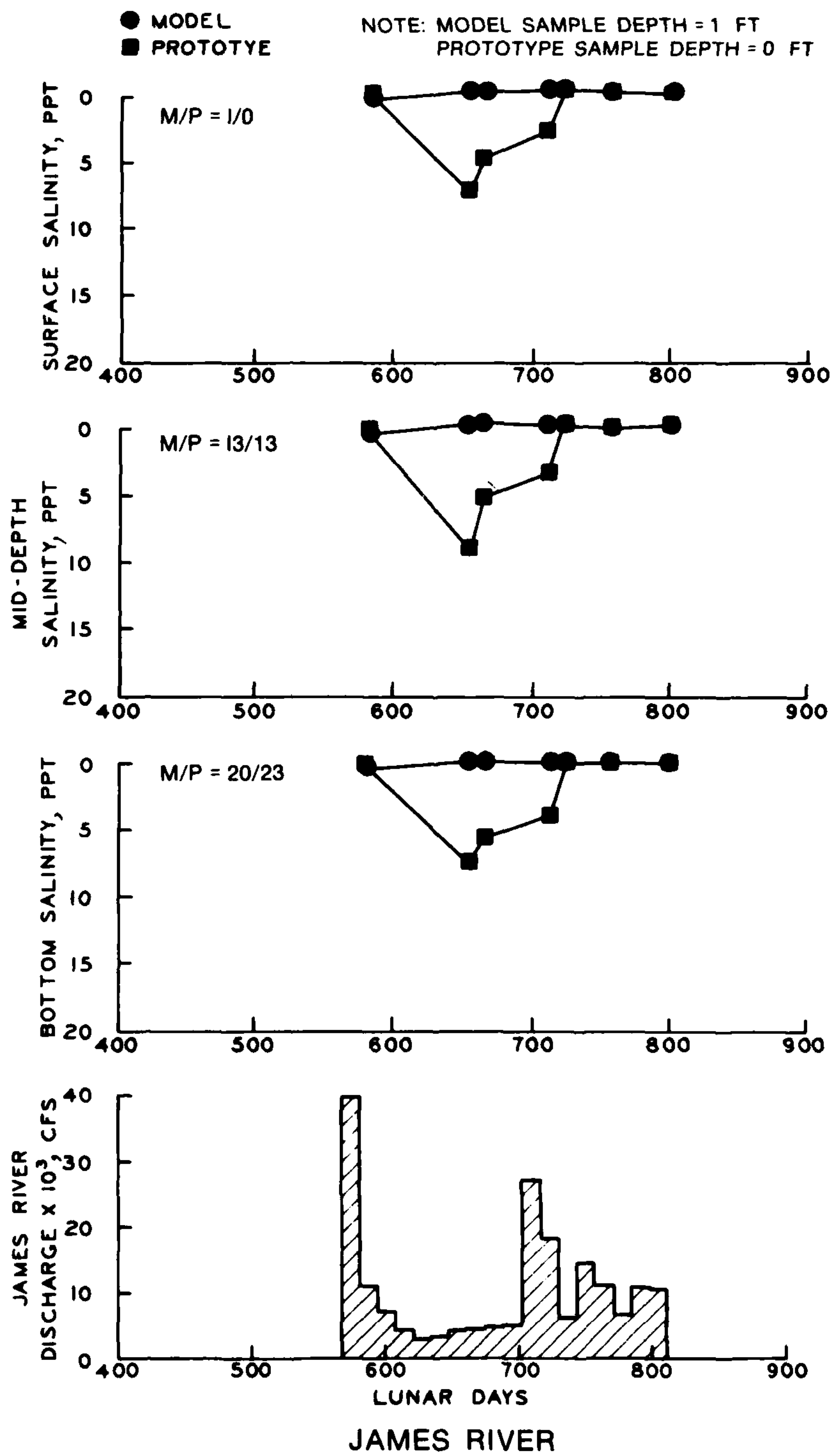



Plate D19. Model/prototype salinity comparison, sta $J_4$, Hydrograph IV

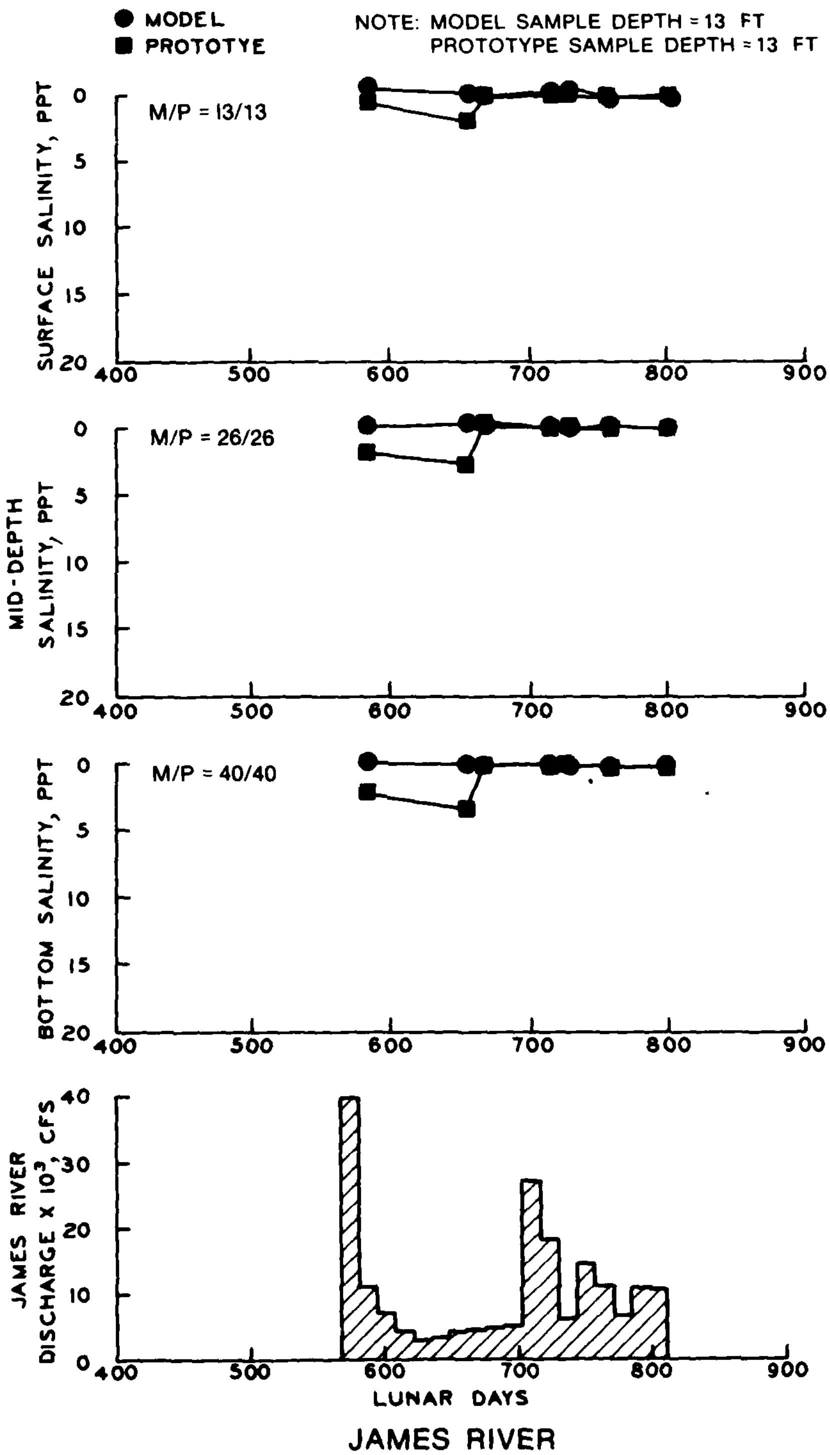



Plate D20. Model/prototype salinity comparison, sta $J_5$, Hydrograph IV

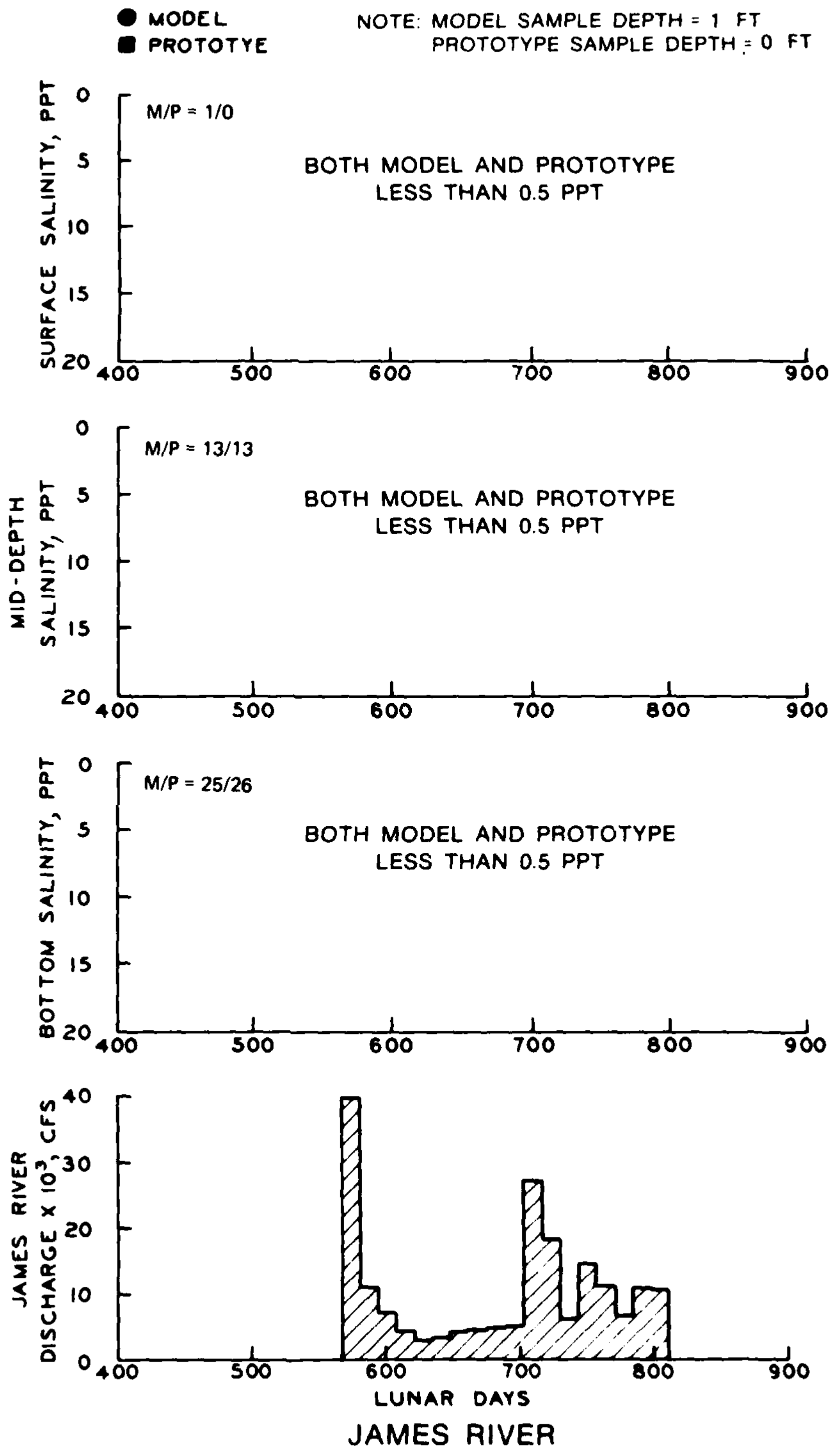



Plate D21. Model/prototype salinity comparison, sta $J_6$, Hydrograph IV

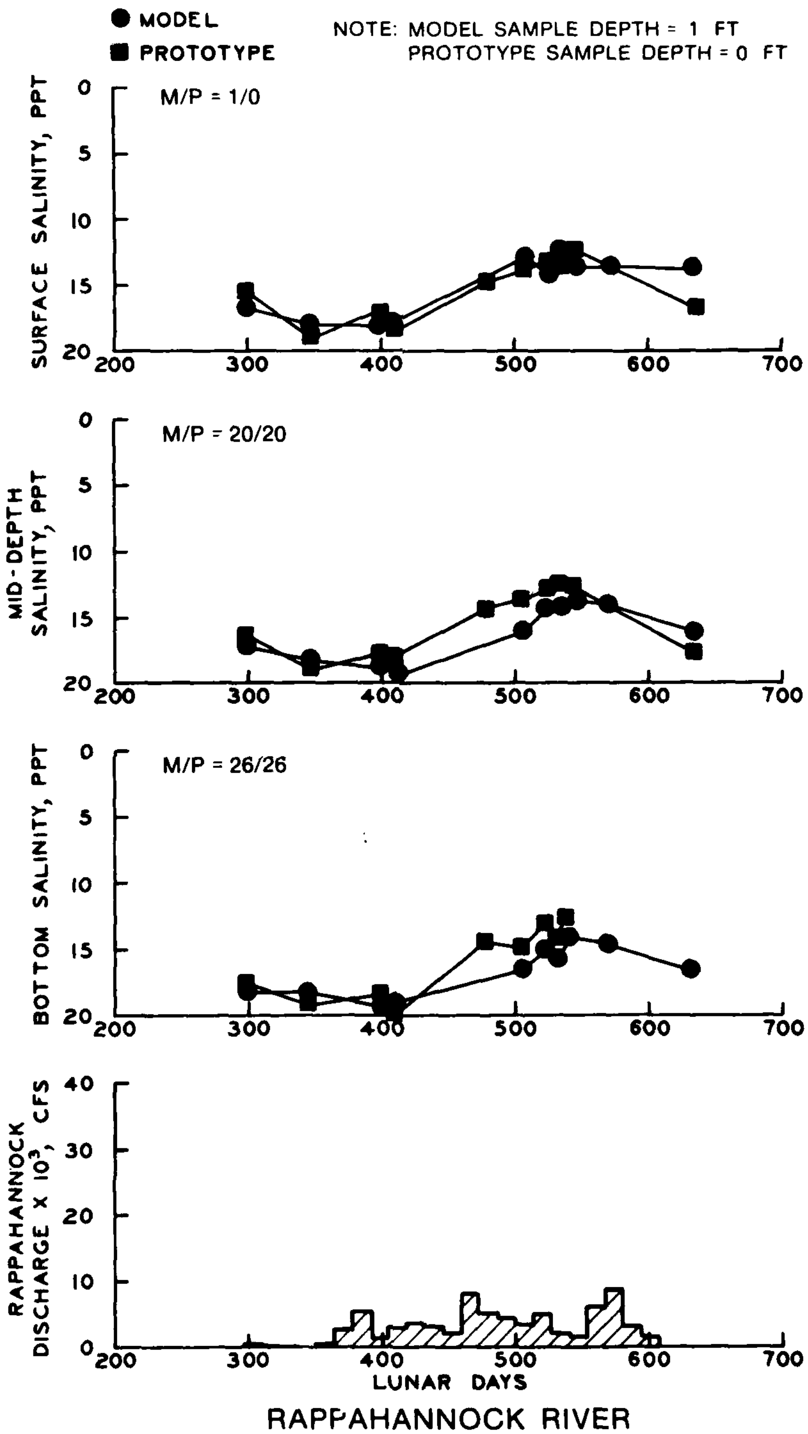



Plate D22. Model/prototype salinity comparison, sta $R_1$, Hydrograph IV

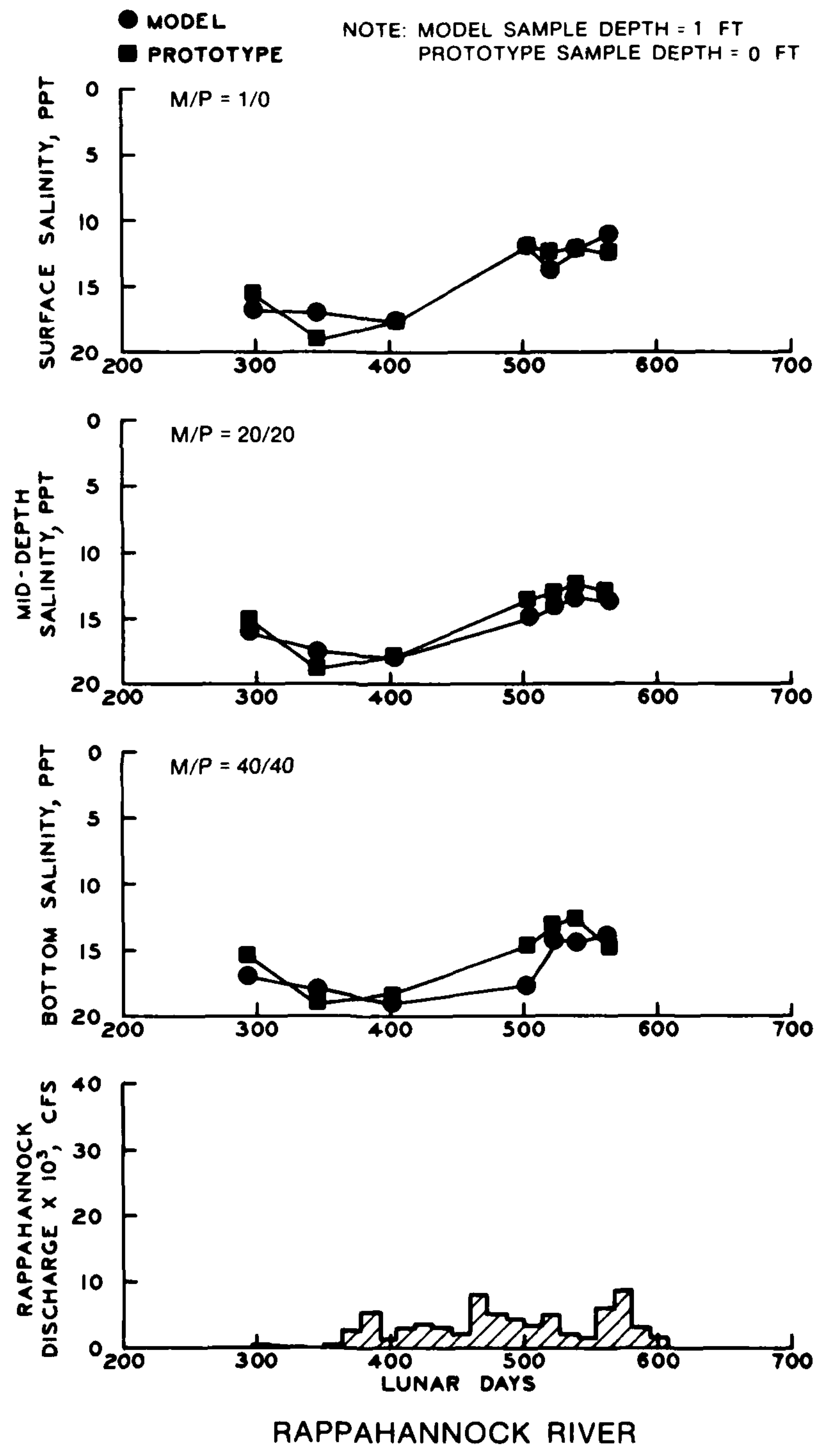



Plate D23. Model/prototype salinity comparison, sta $R_2$, Hydrograph IV

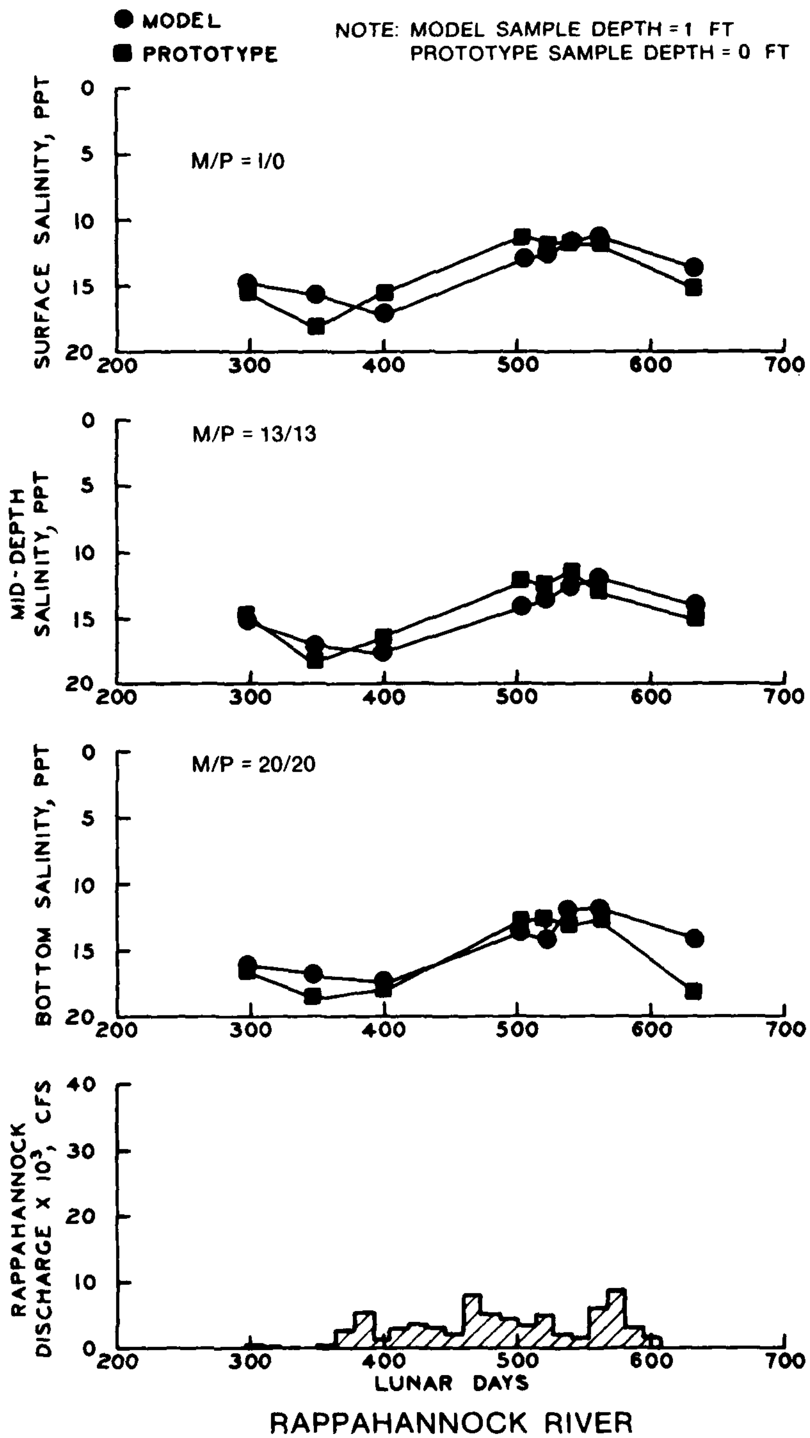



Plate D24. Model/prototype salinity comparison, sta $R_3$, Hydrograph IV

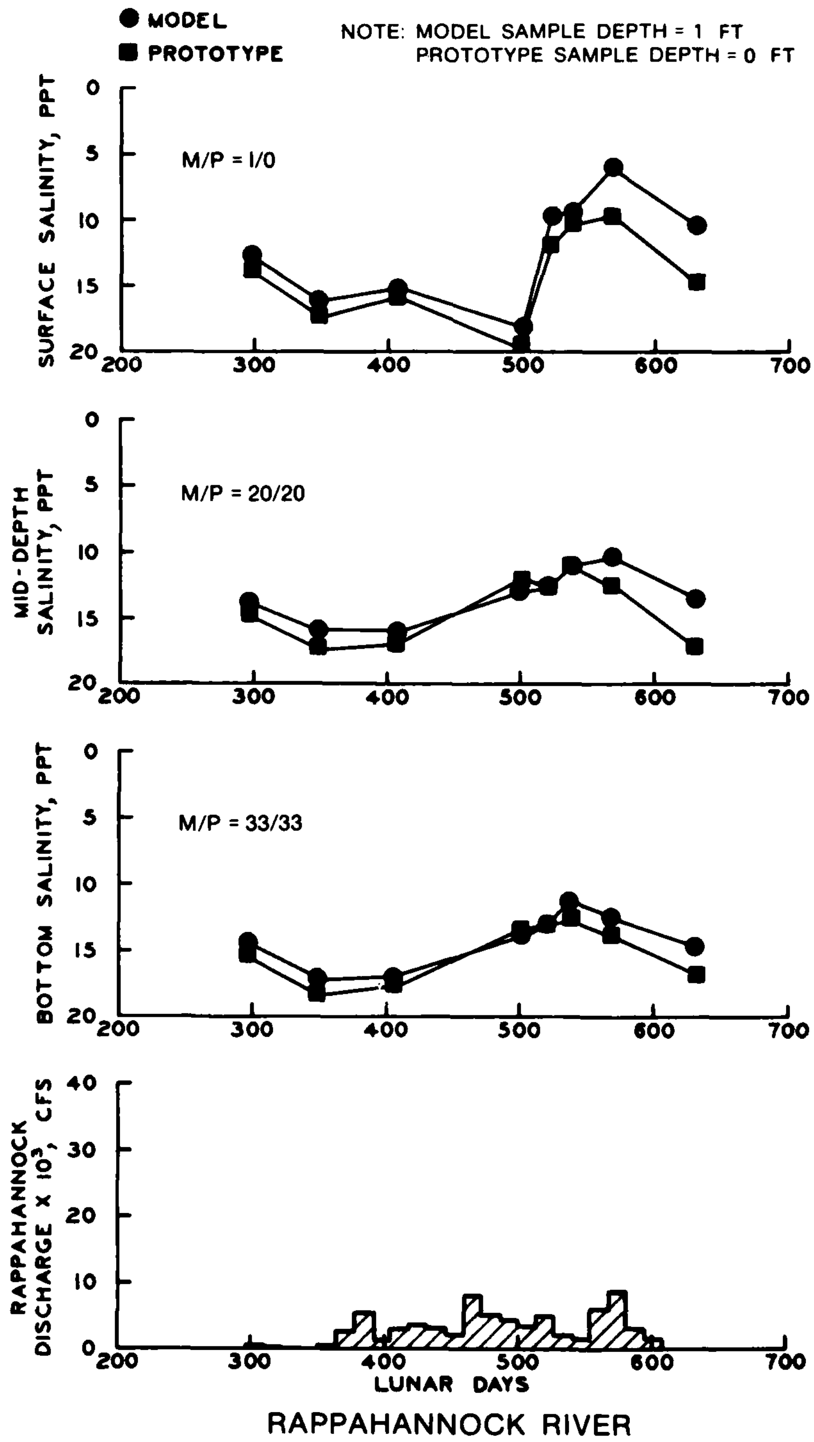



Plate D25. Model/prototype salinity comparison, sta $R_4$, Hydrograph IV

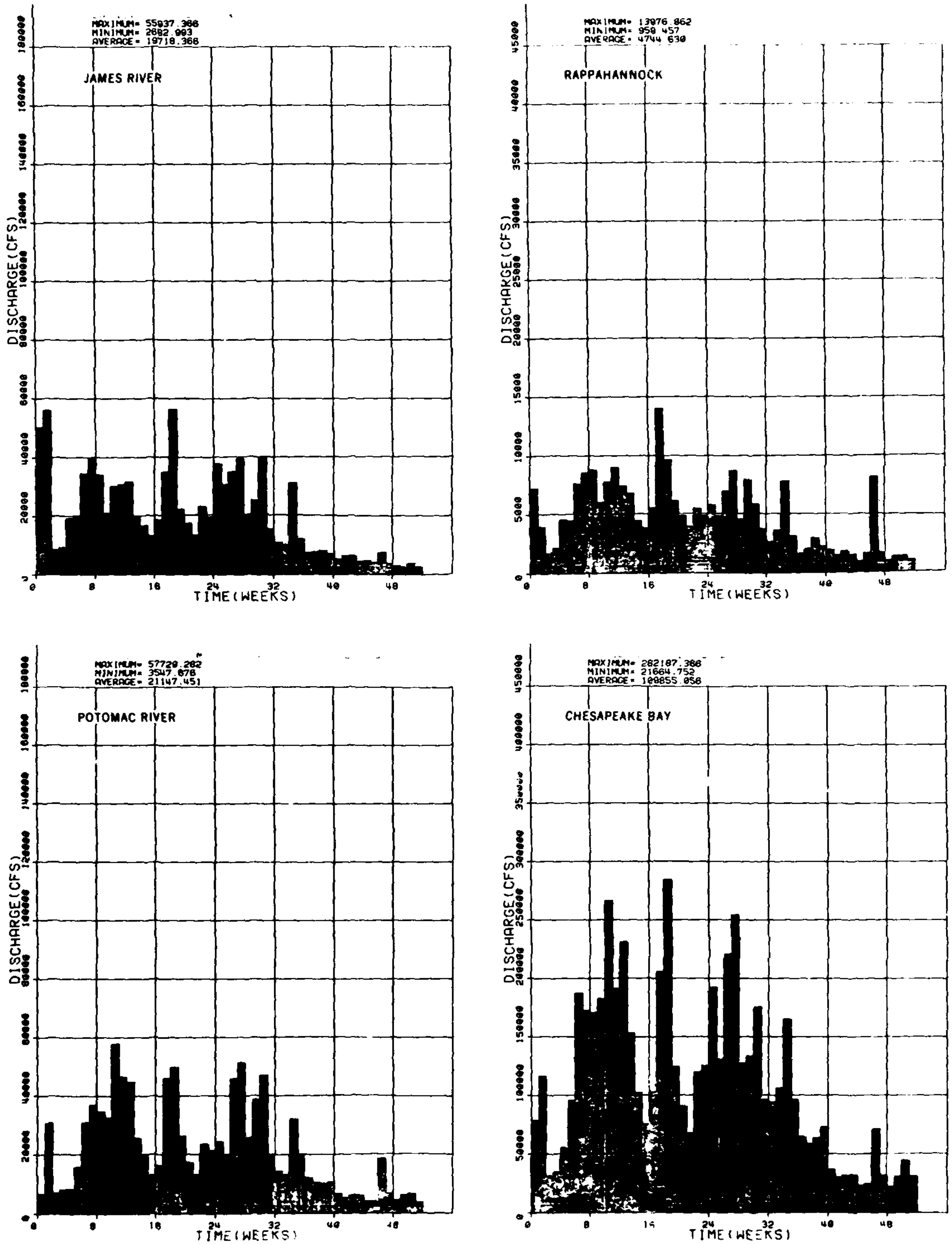



Plate D2. Freshwater inflow hydrographs, 1 Oct 1970-30 Sep 1971

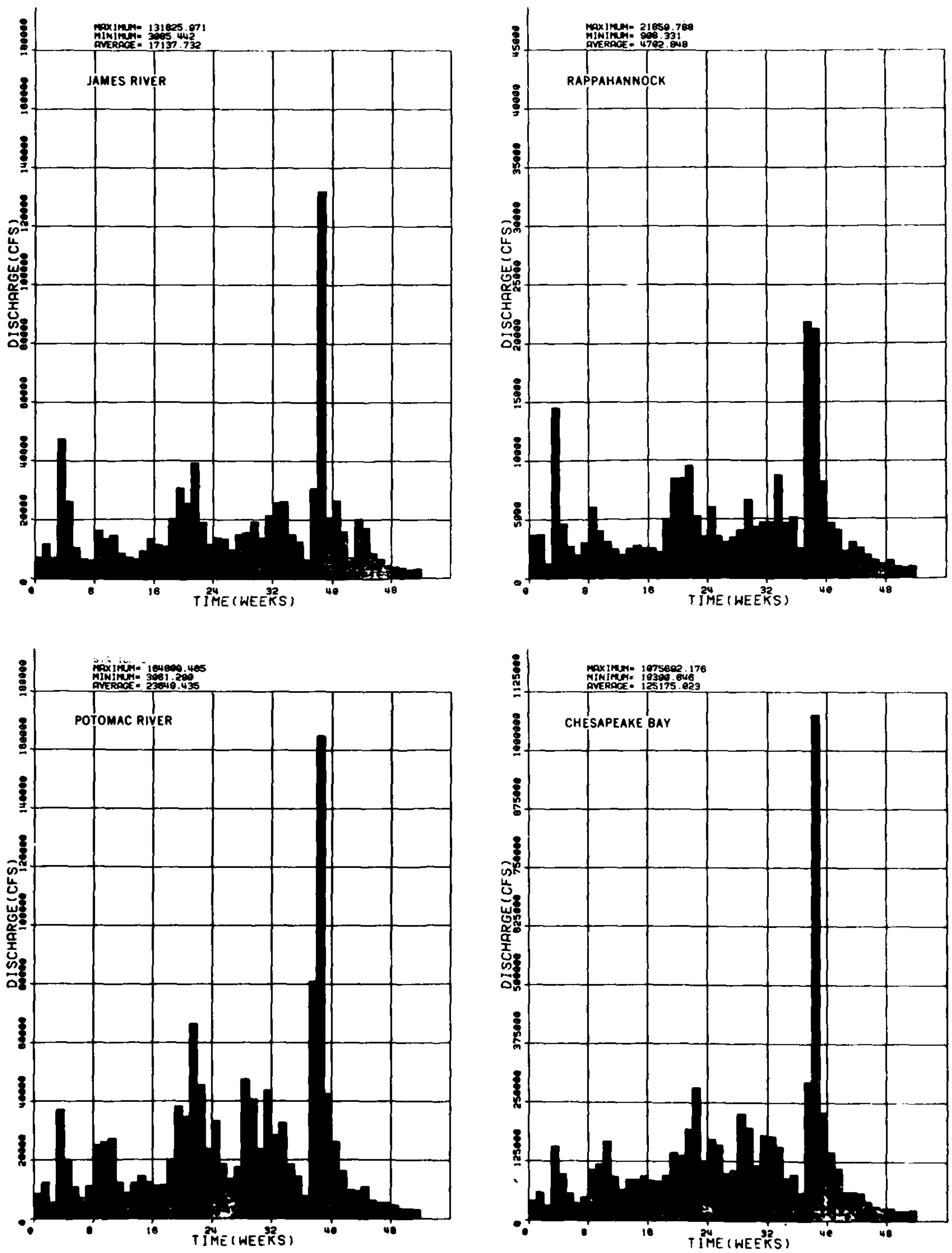



Plate D3. Freshwater inflow hydrographs, 1 Oct 1981-30 Sep 1972

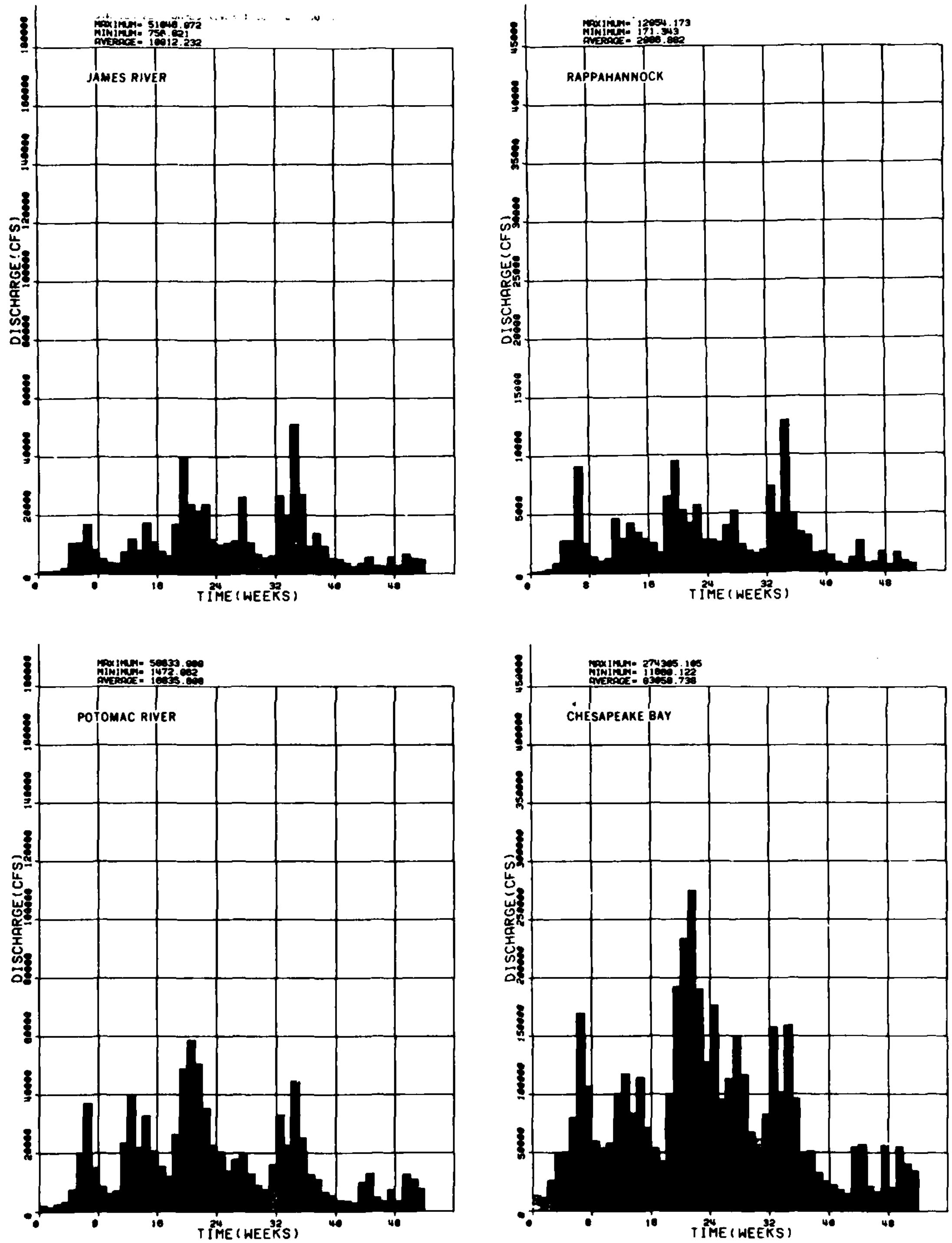



Plate D4. Freshwater inflow hydrographs, 1 Oct 1972-30 Sep 1973

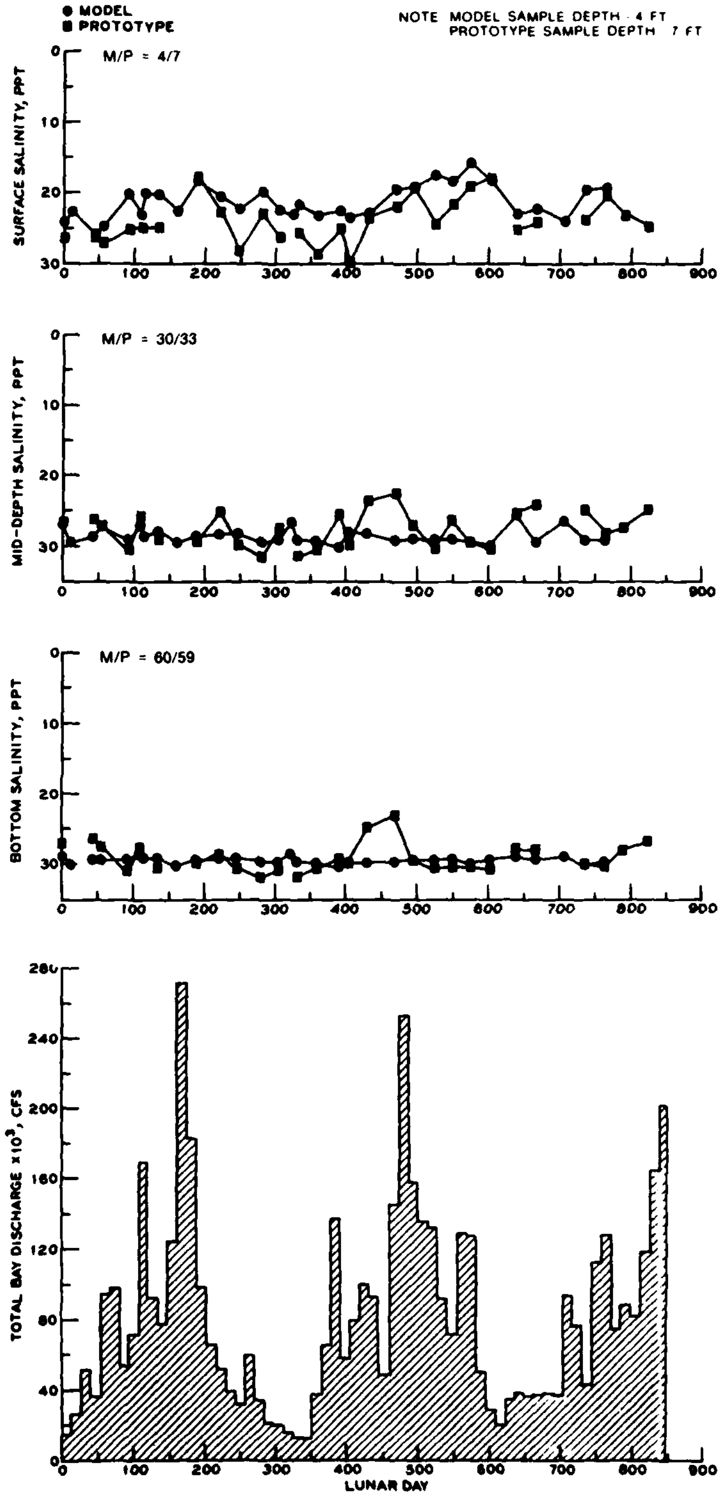



Plate D5. Model/prototype salinity comparison, sta A, Hydrograph IV

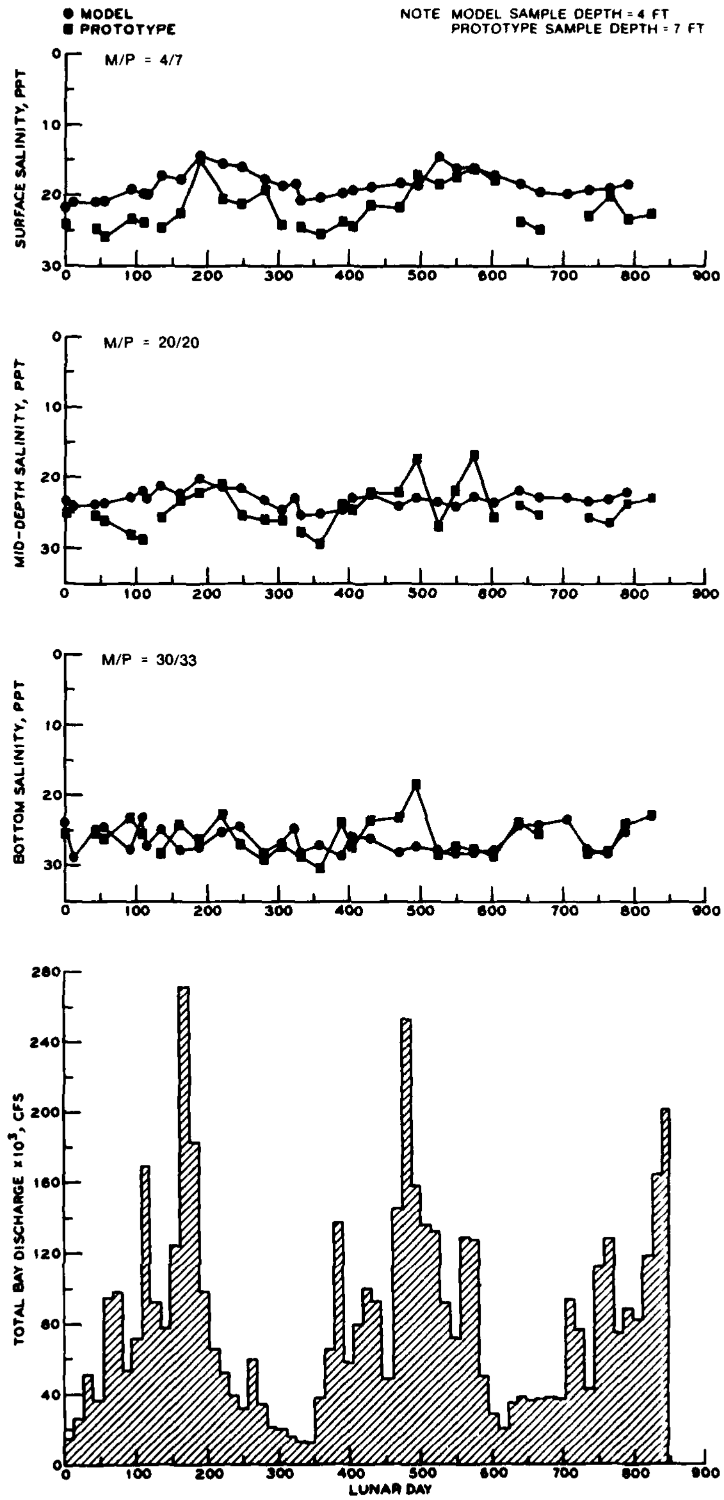



Plate D6. Model/prototype salinity comparison, sta B, Hydrograph IV

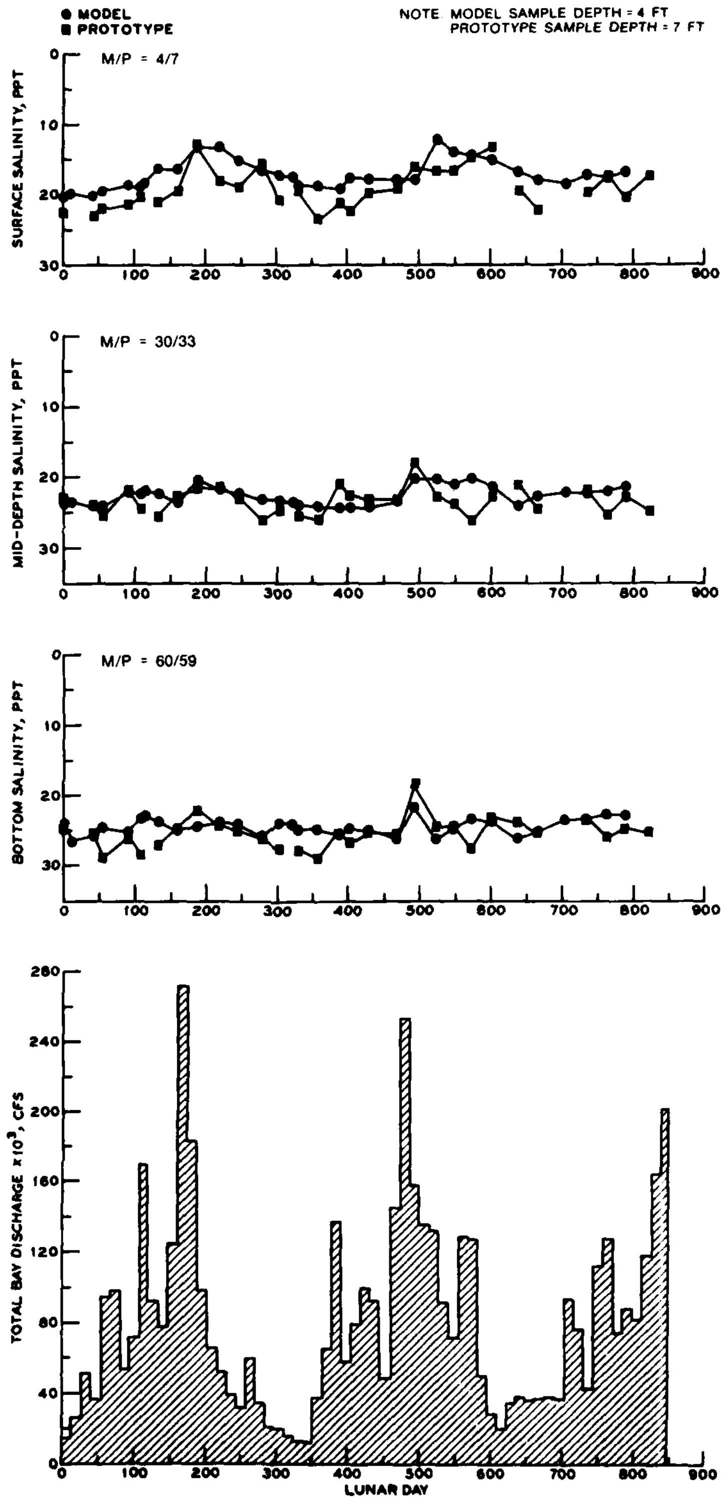



Plate D7. Model/prototype salinity comparison, sta C, Hydrograph IV

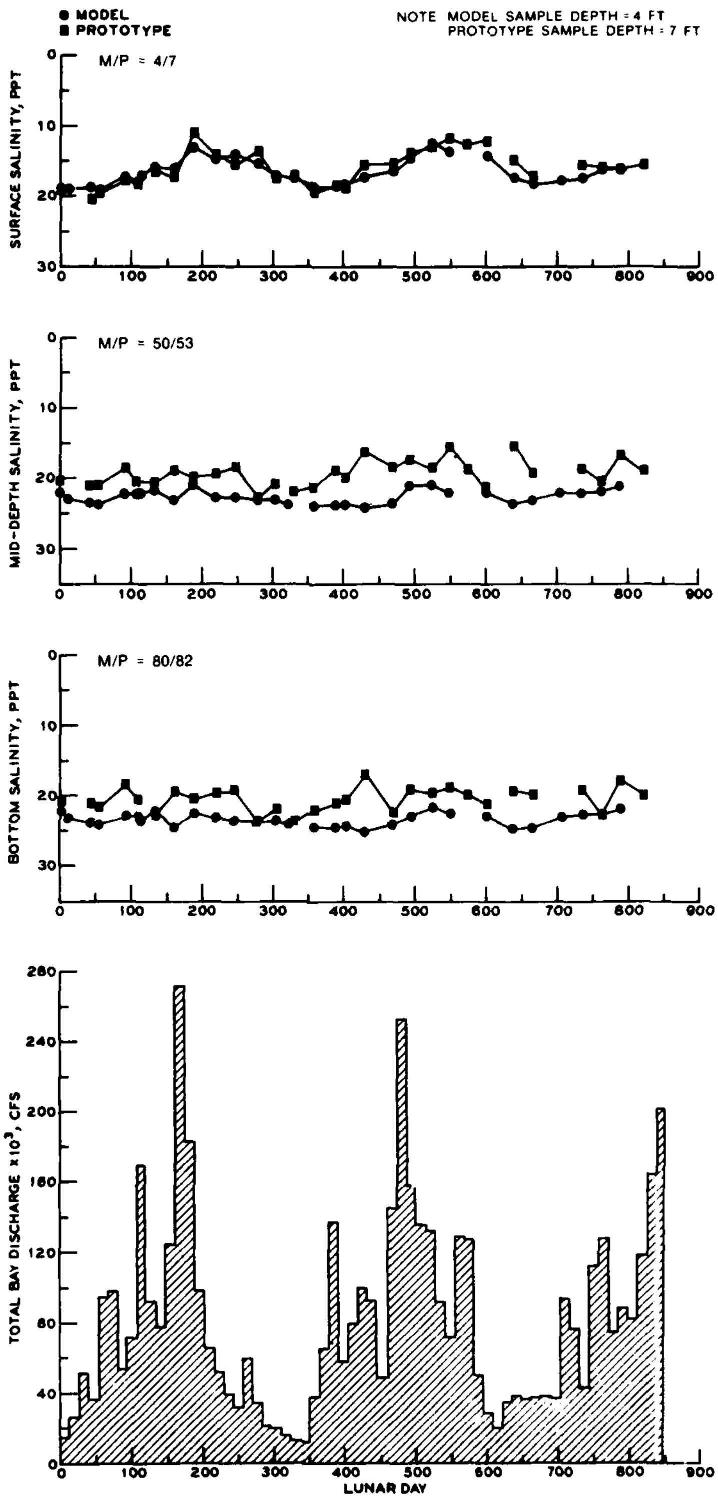



Plate D8. Model/prototype salinity comparison, sta D, Hydrograph IV

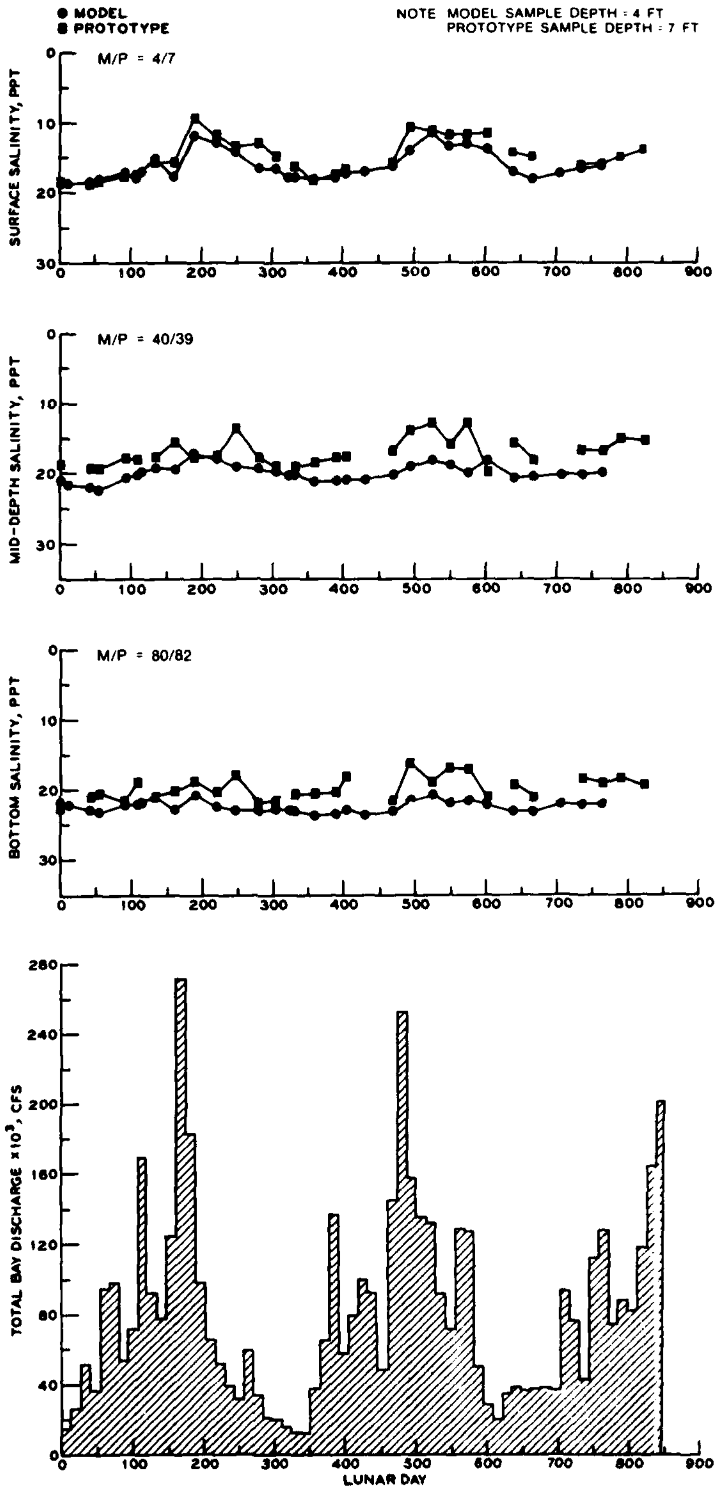



Plate D9. Model/prototype salinity comparison, sta E, Hydrograph IV

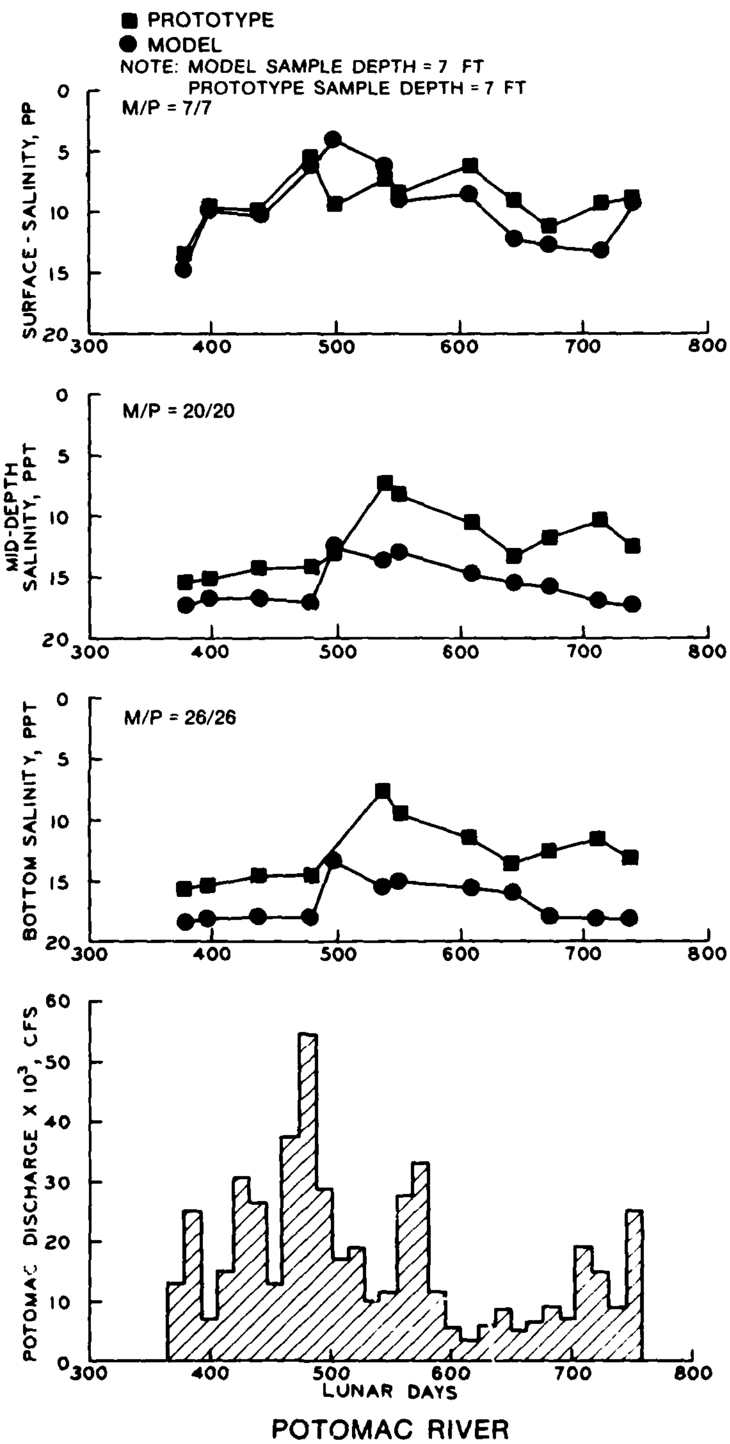



Plate D34. Model/prototype salinity comparison, sta $PO_{22}$, Hydrograph IV

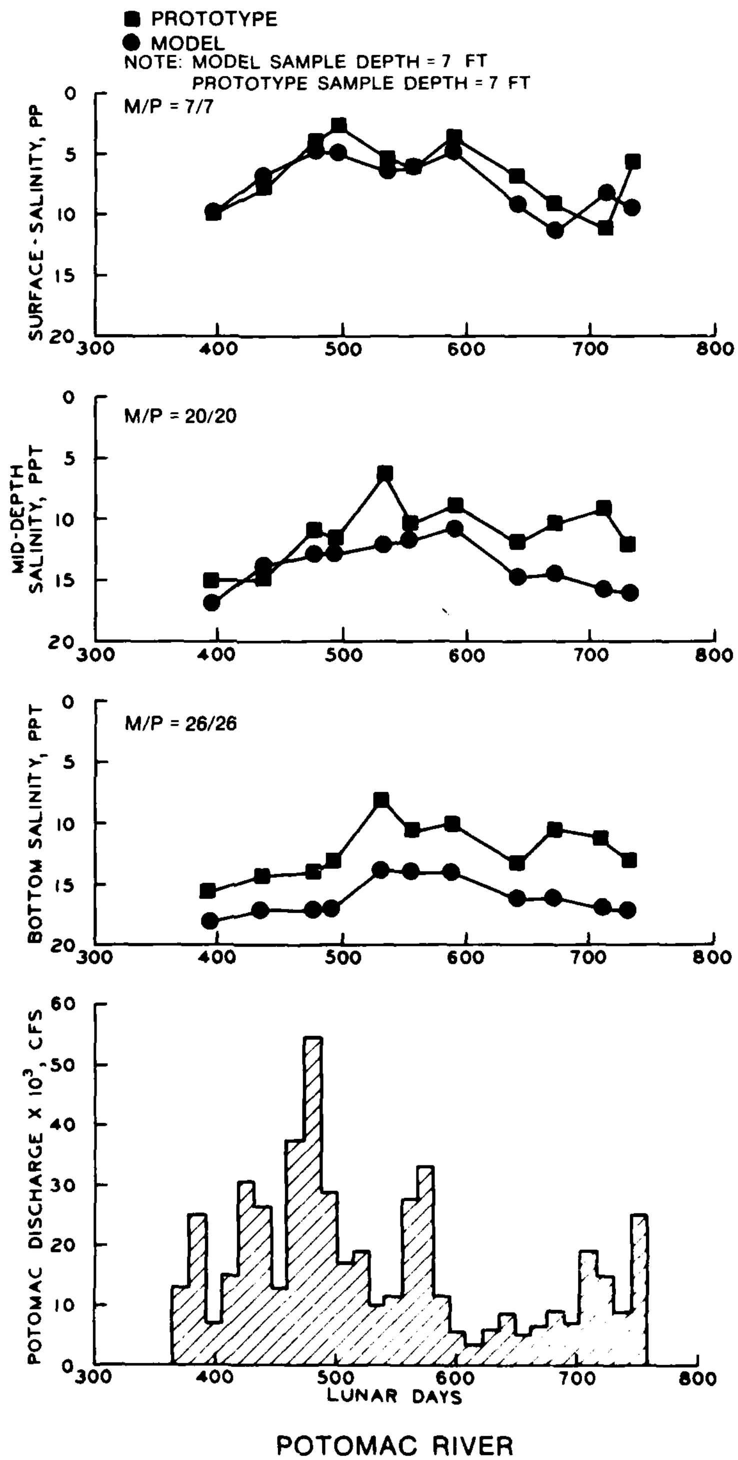



Plate D35. Model/prototype salinity comparison, sta $PO_{29}$, Hydrograph IV

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VERIFICATION OF THE CHESAPEAKE BAY MODEL.(U)
DEC 81 N W SCHEFFNER, L G CROSBY, D F BASTIAN

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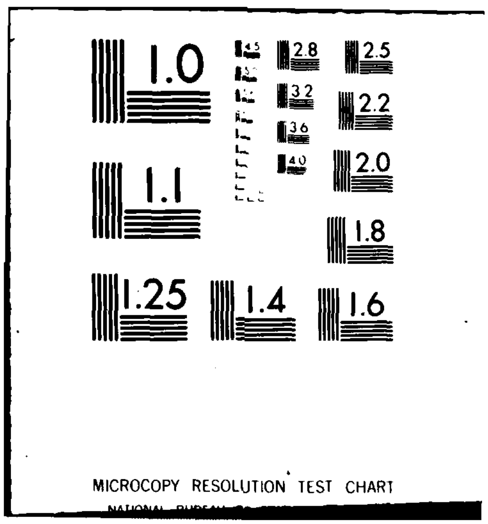
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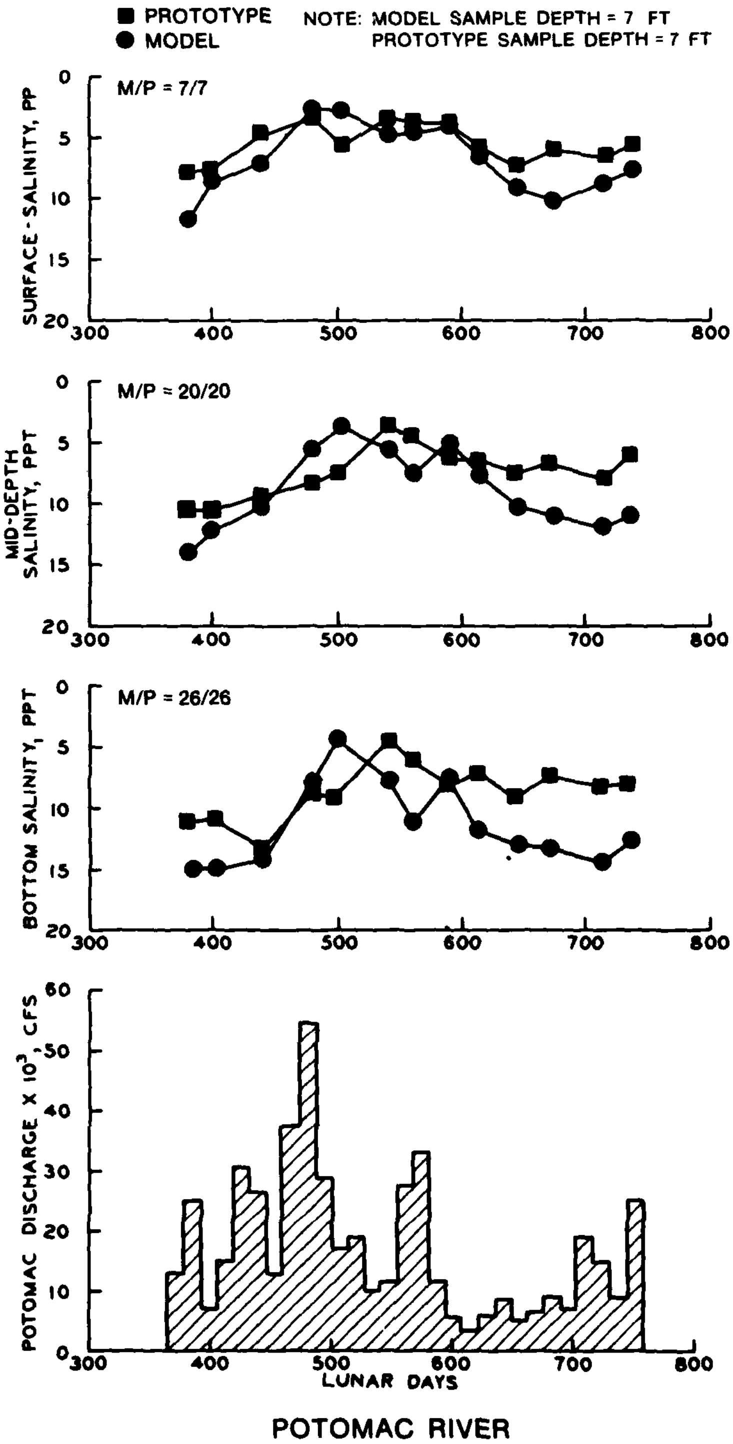
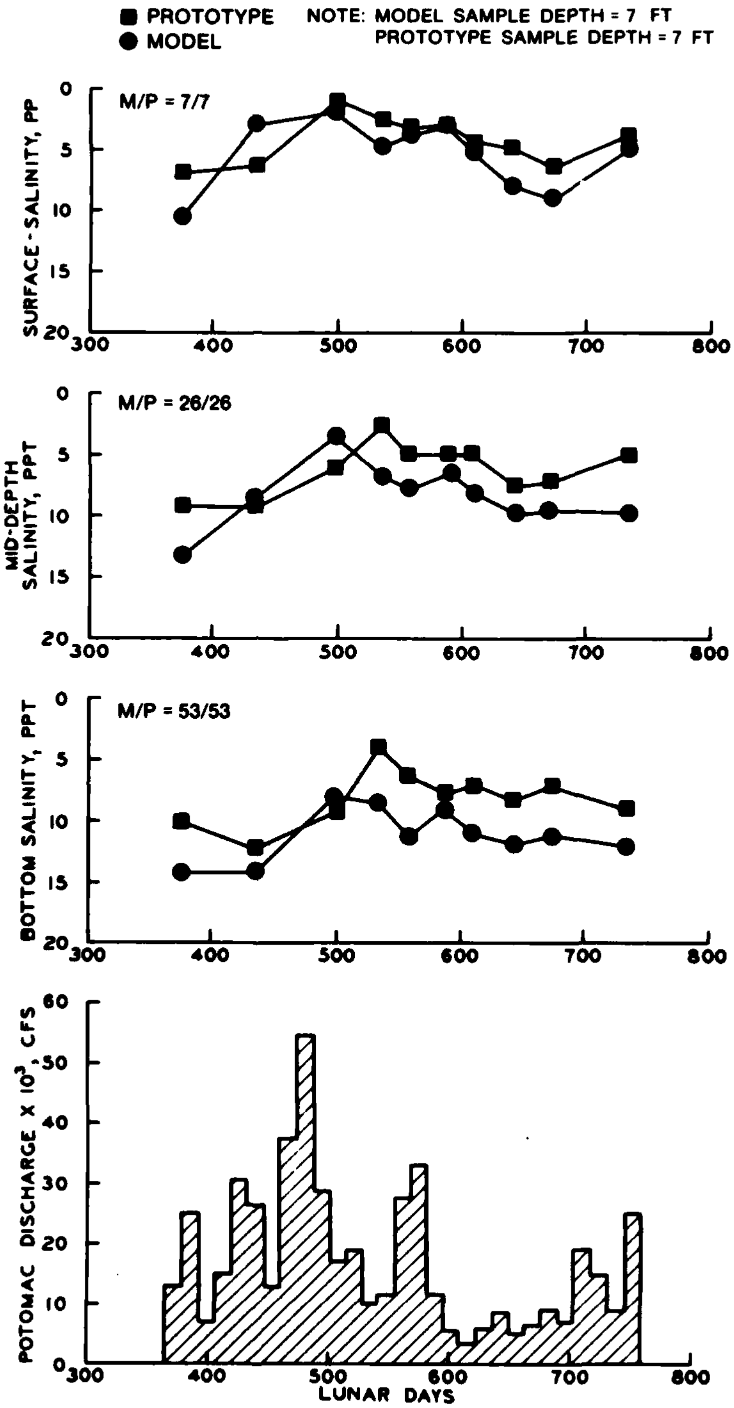



Plate D36. Model/prototype salinity comparison, sta $PO_{35}$, Hydrograph IV




POTOMAC RIVER

Plate D37. Model/prototype salinity comparison, sta $PO_{40}$, Hydrograph IV

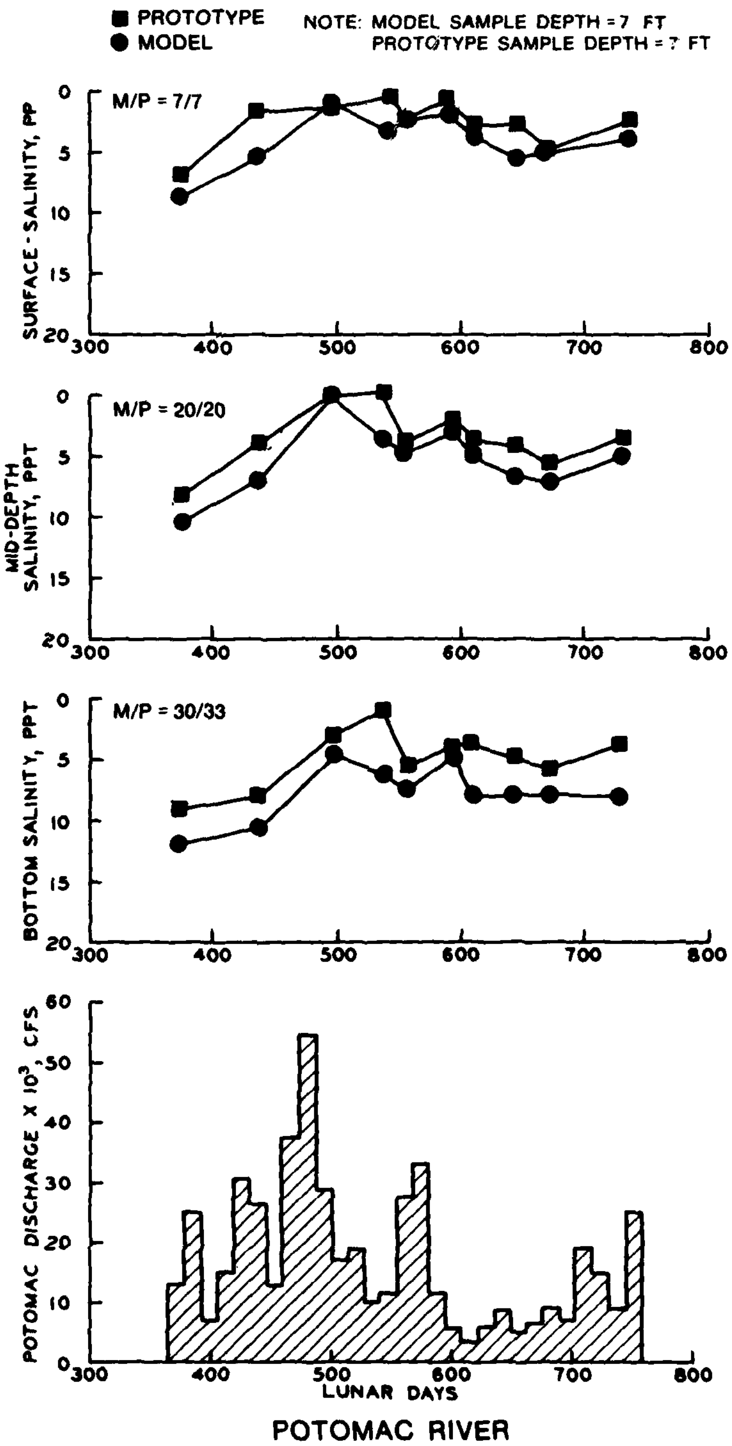



Plate D38. Model/prototype salinity comparison, sta $PO_{46}$, Hydrograph IV

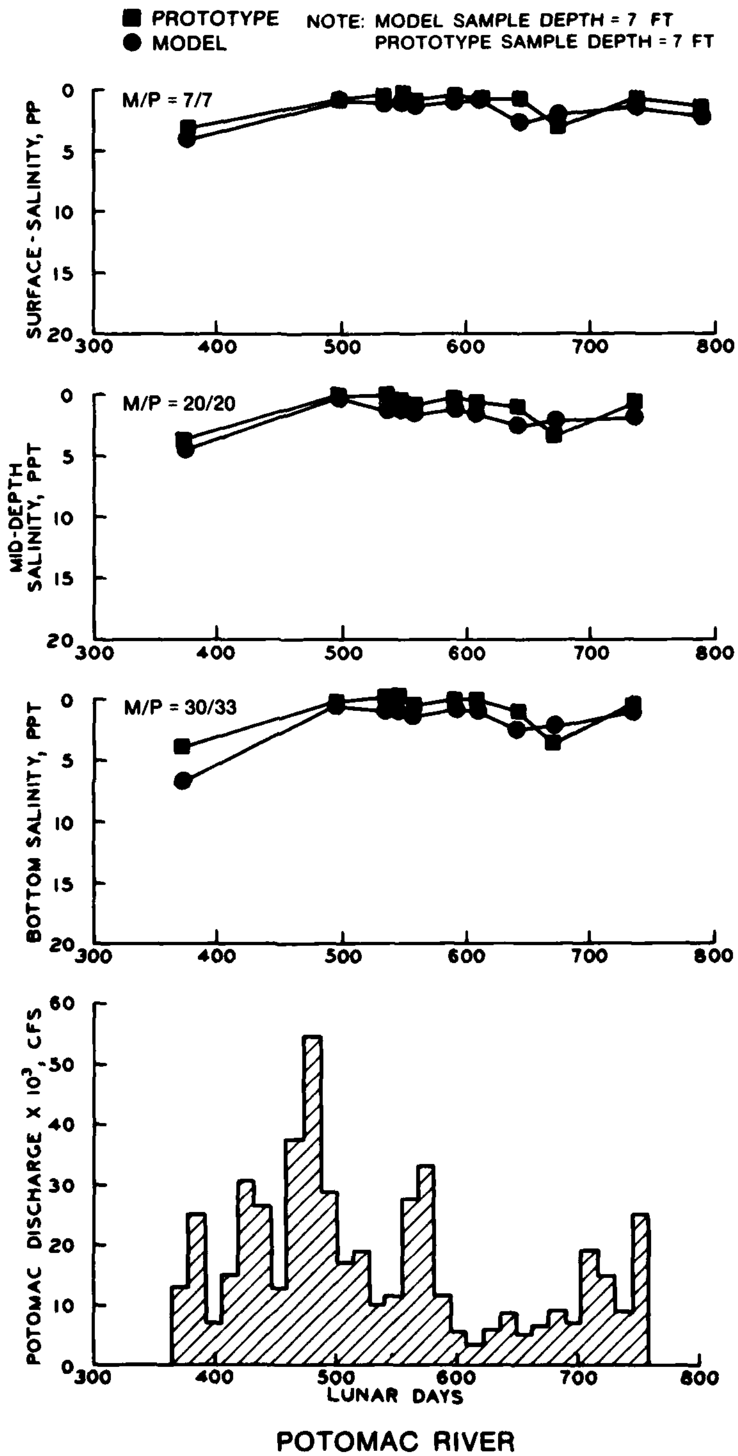



Plate D39. Model/prototype salinity comparison, sta $PO_{52}$, Hydrograph IV

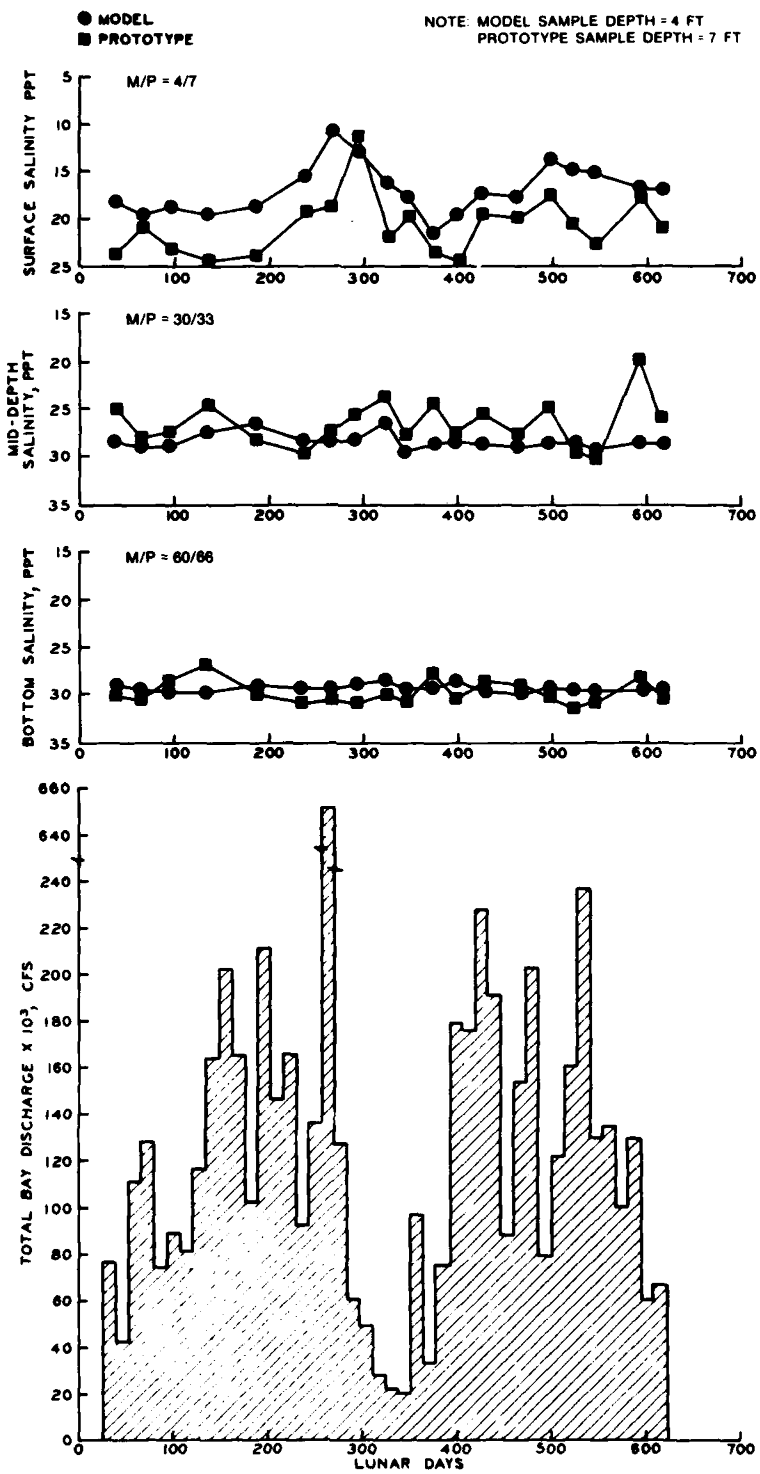



Plate D40. Model/prototype salinity comparison, sta A, Hydrograph III

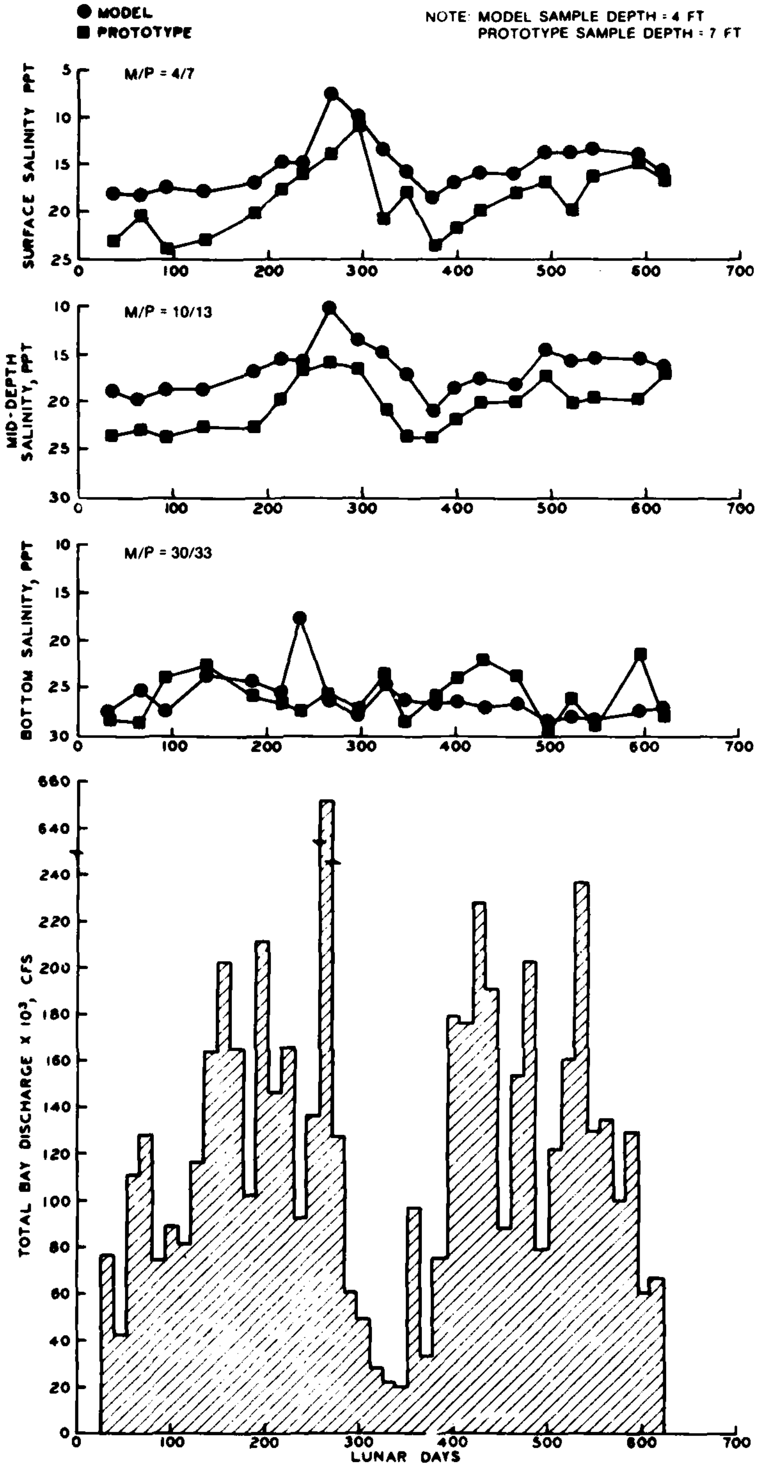



Plate D41. Model/prototype salinity comparison, sta B, Hydrograph III

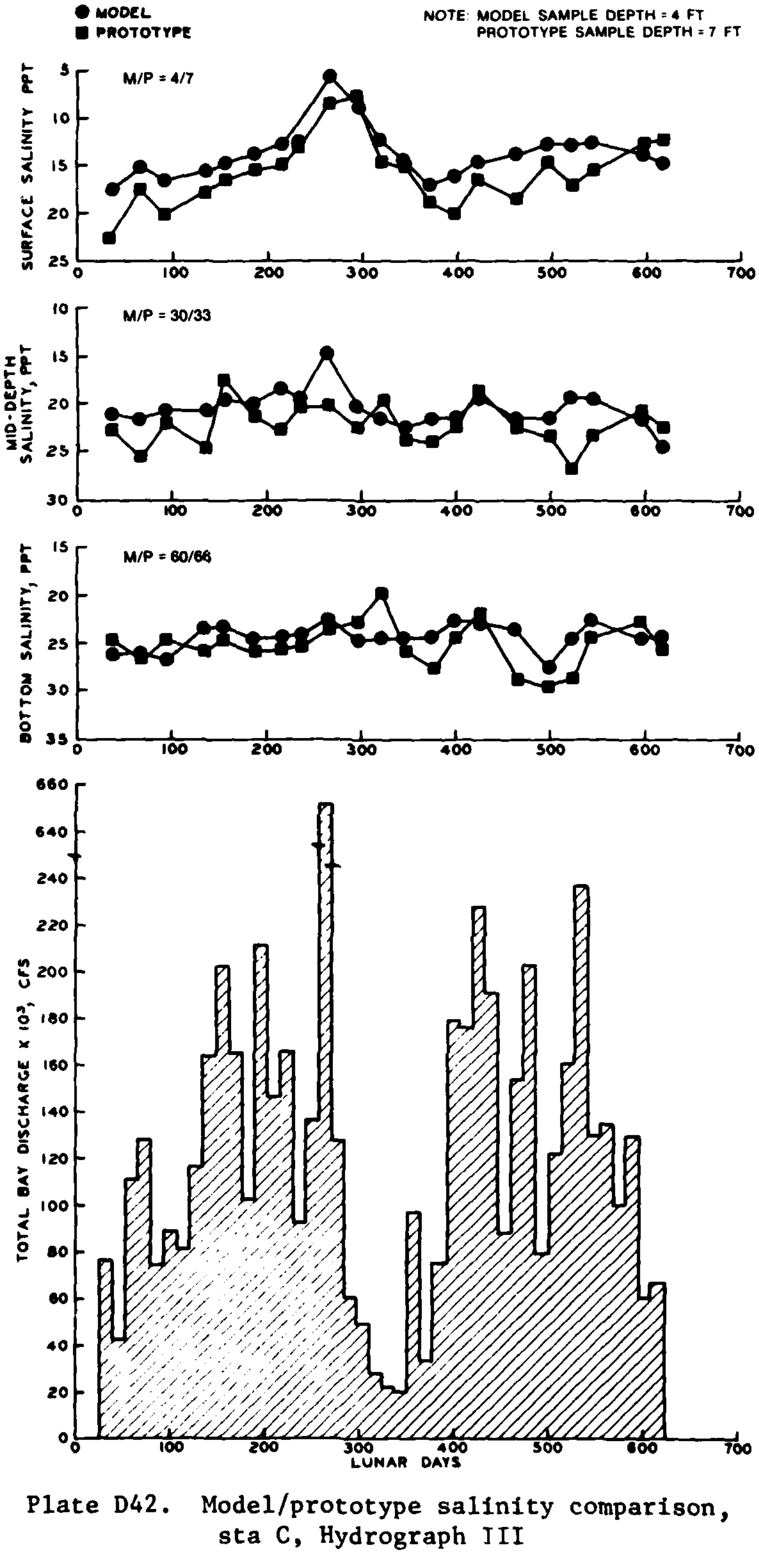



Plate D42. Model/prototype salinity comparison, sta C, Hydrograph III

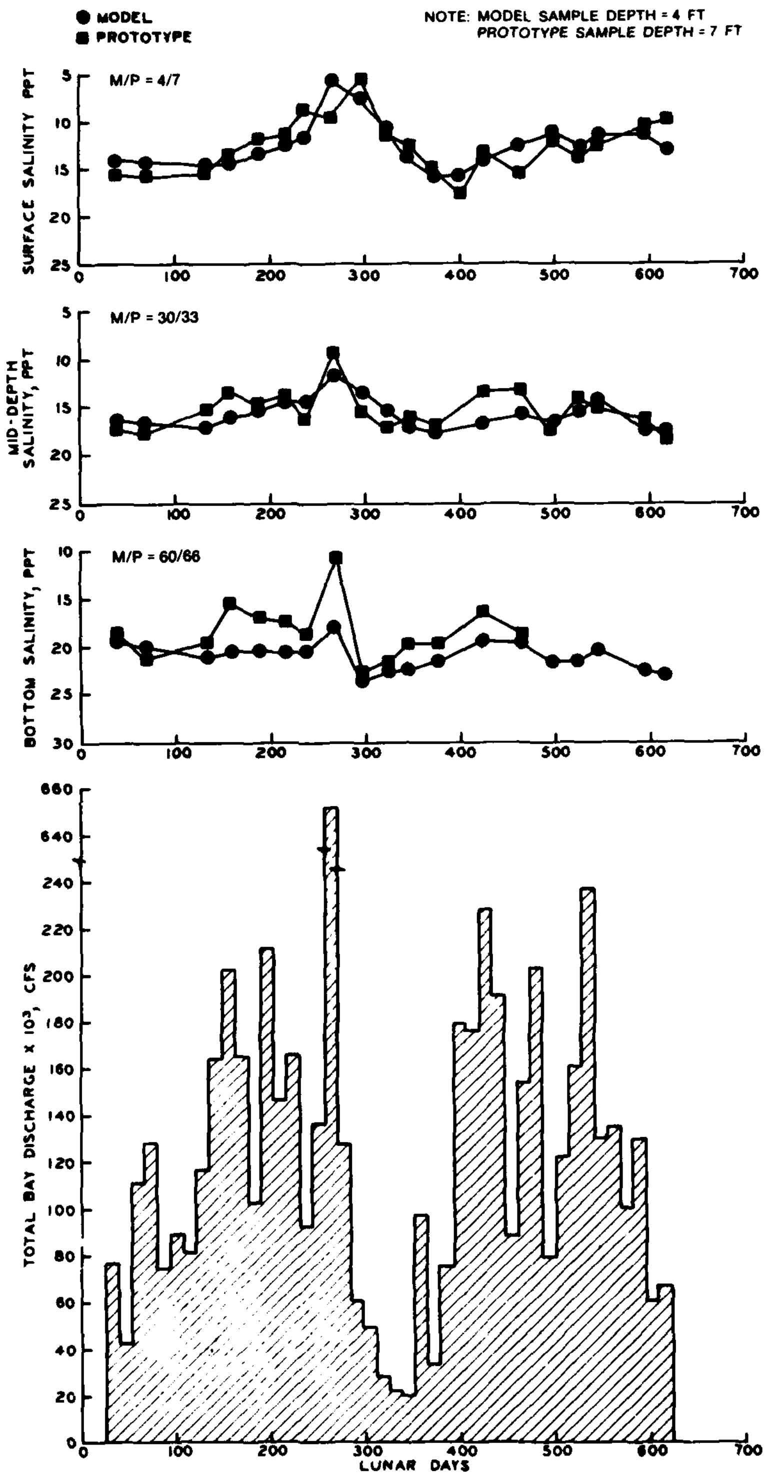



Plate D43. Model/prototype salinity comparison, sta D, Hydrograph III

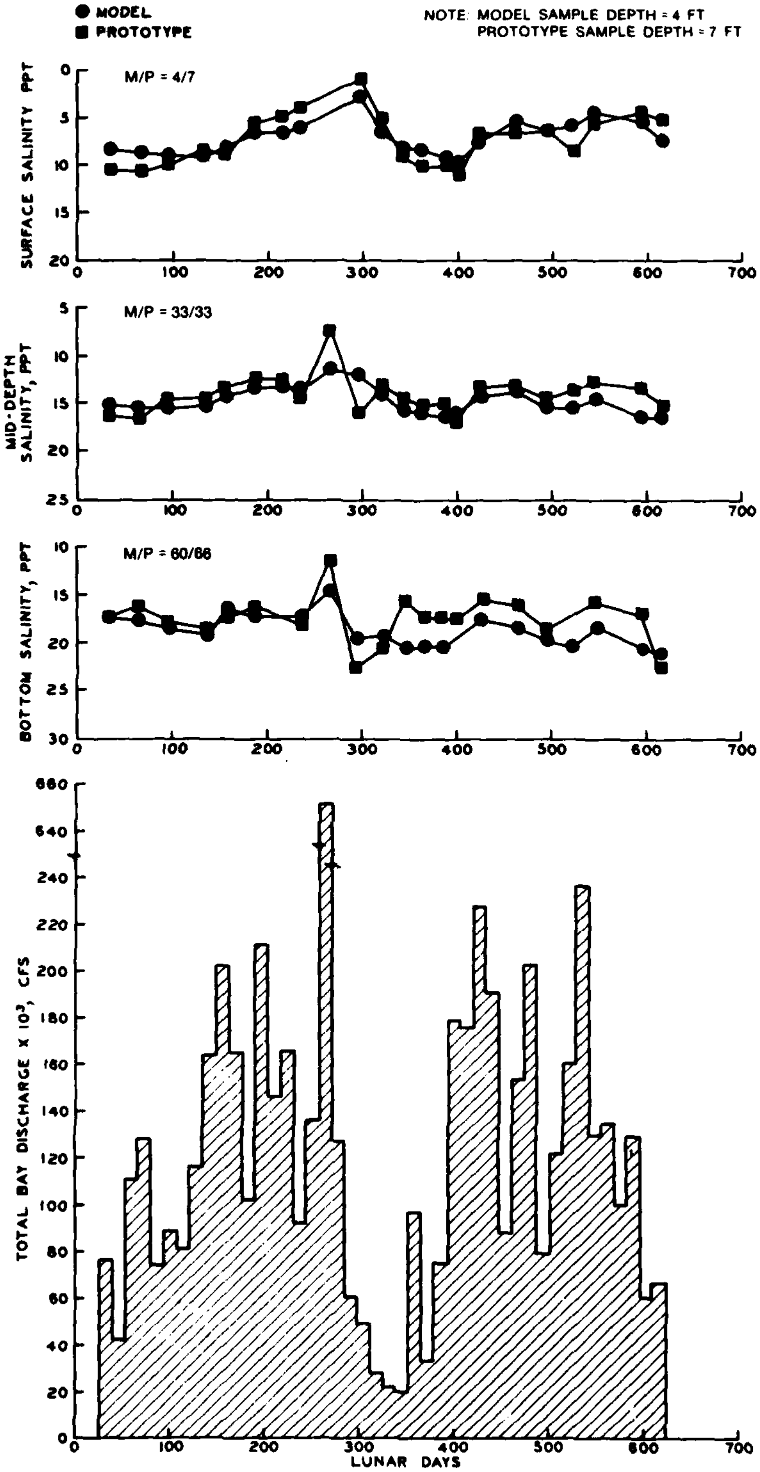



Plate D44. Model/prototype salinity comparison, sta E, Hydrograph III

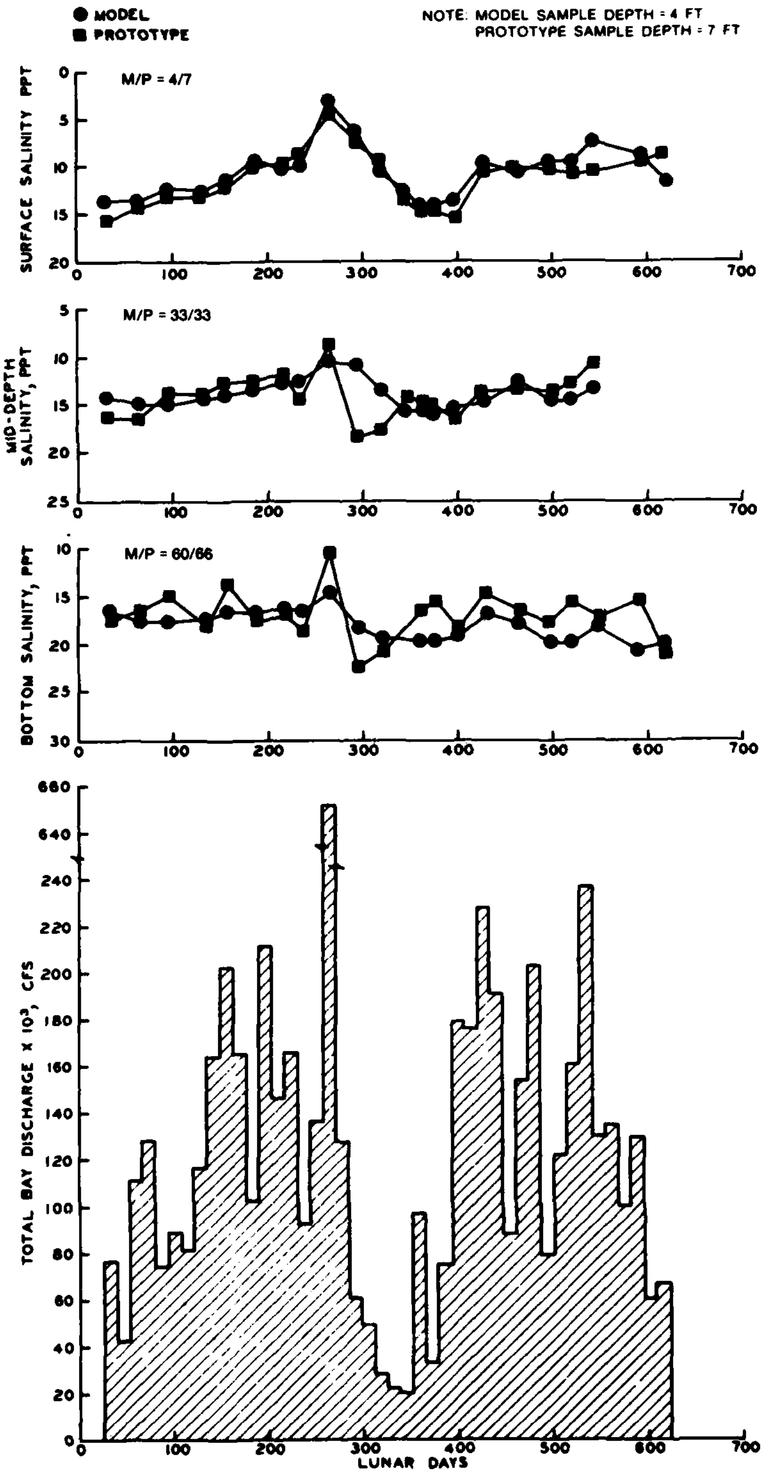



Plate D45. Model/prototype salinity comparison, sta F, Hydrograph III

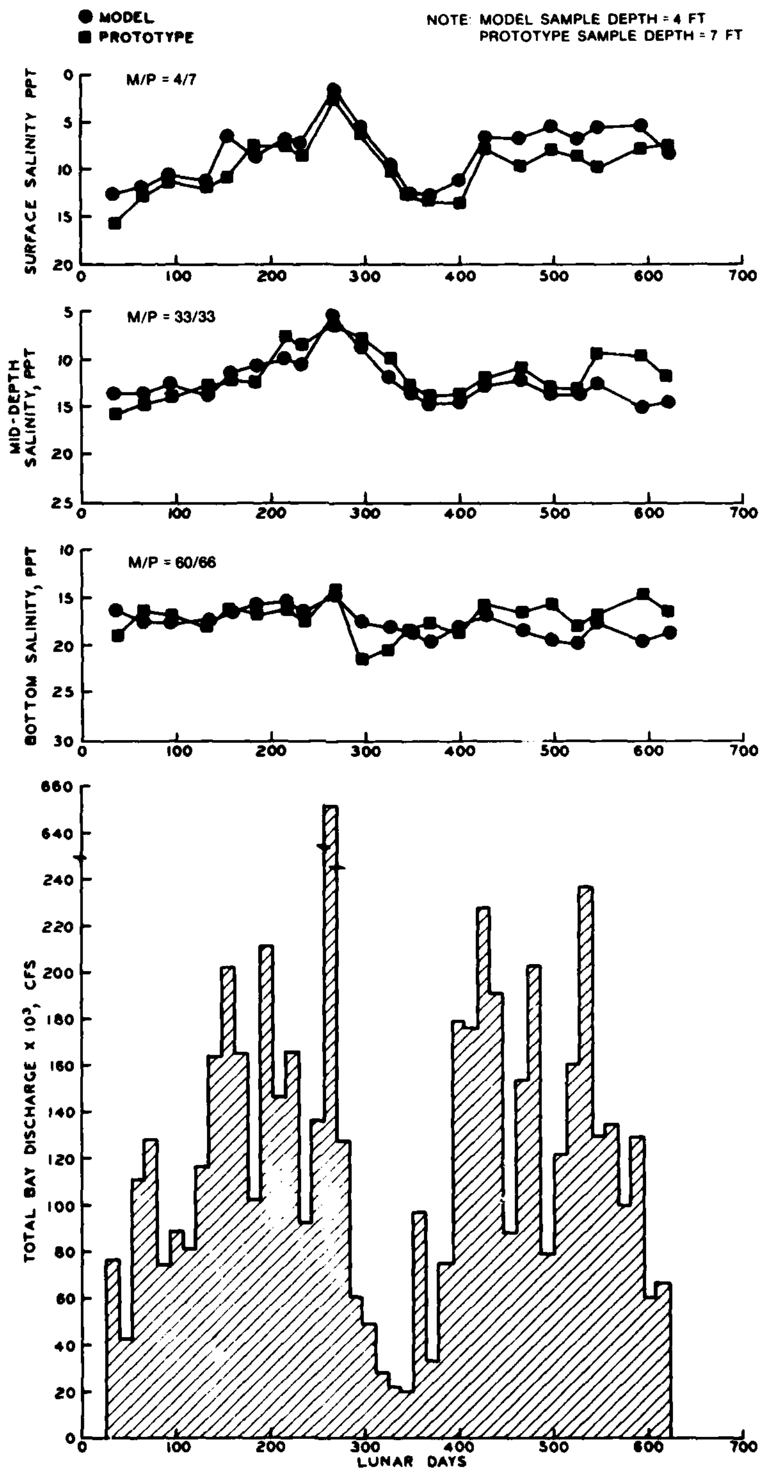



Plate D46. Model/prototype salinity comparison, sta G, Hydrograph III

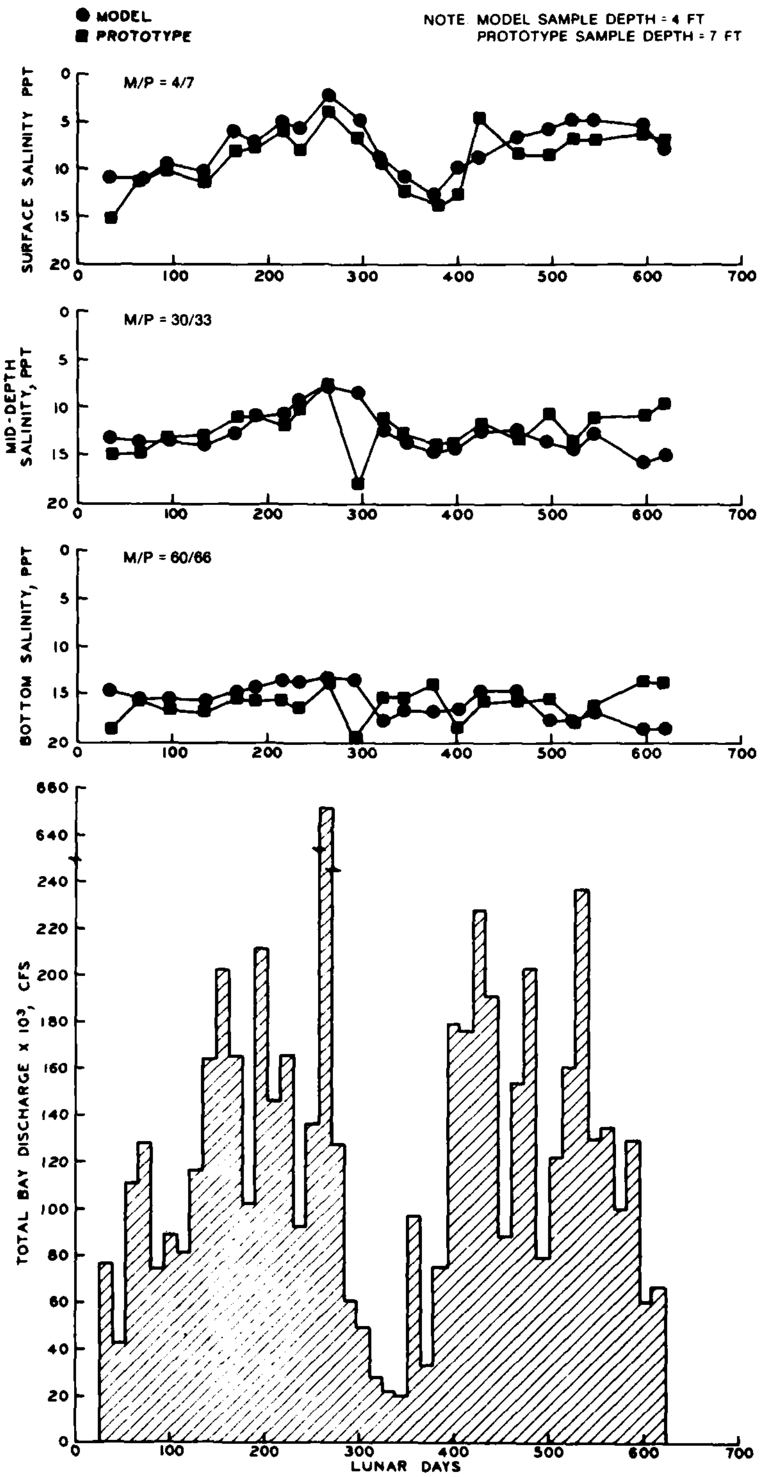



Plate D47. Model/prototype salinity comparison, sta H, Hydrograph III

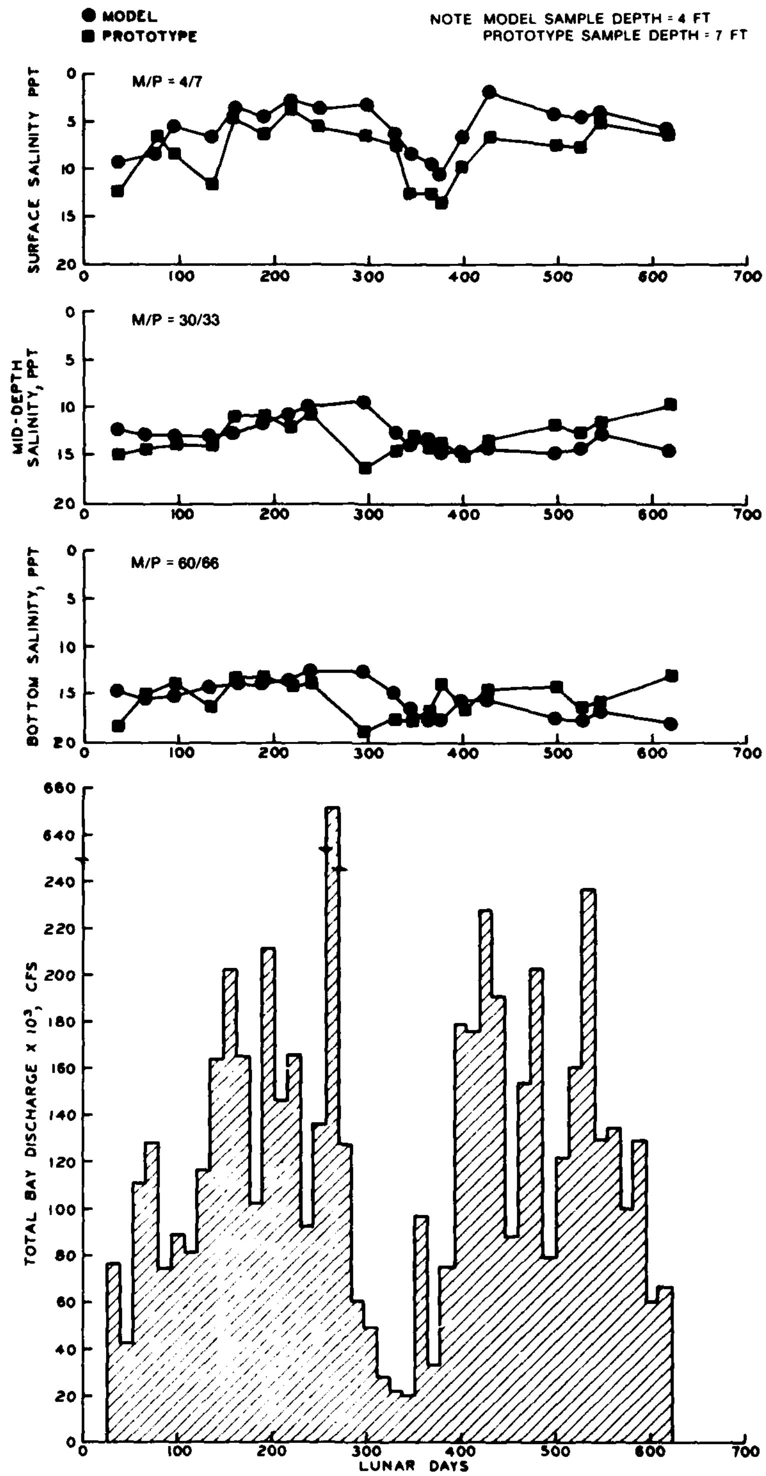



Plate D48. Model/prototype salinity comparison, sta I, Hydrograph III

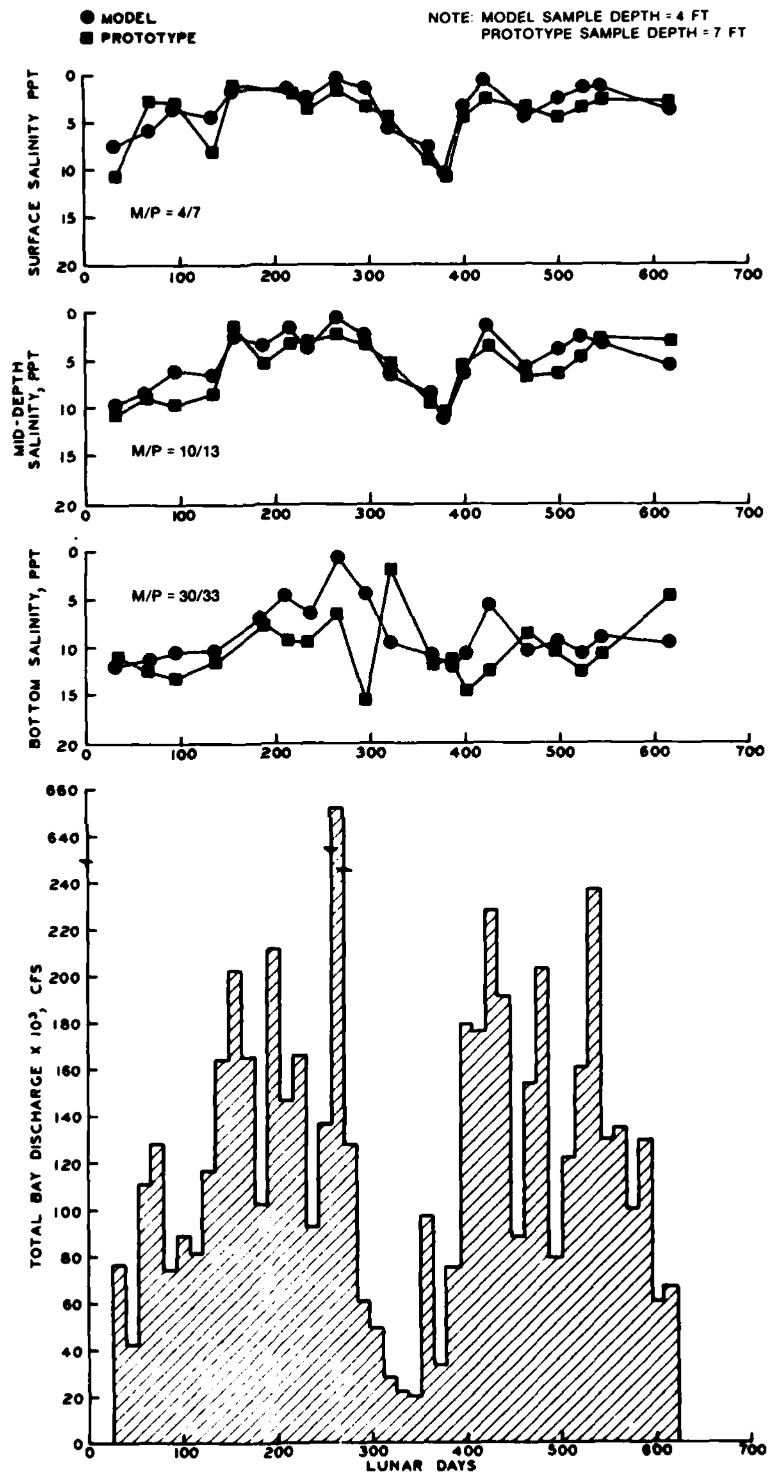



Plate D49. Model/prototype salinity comparison, sta J, Hydrograph III

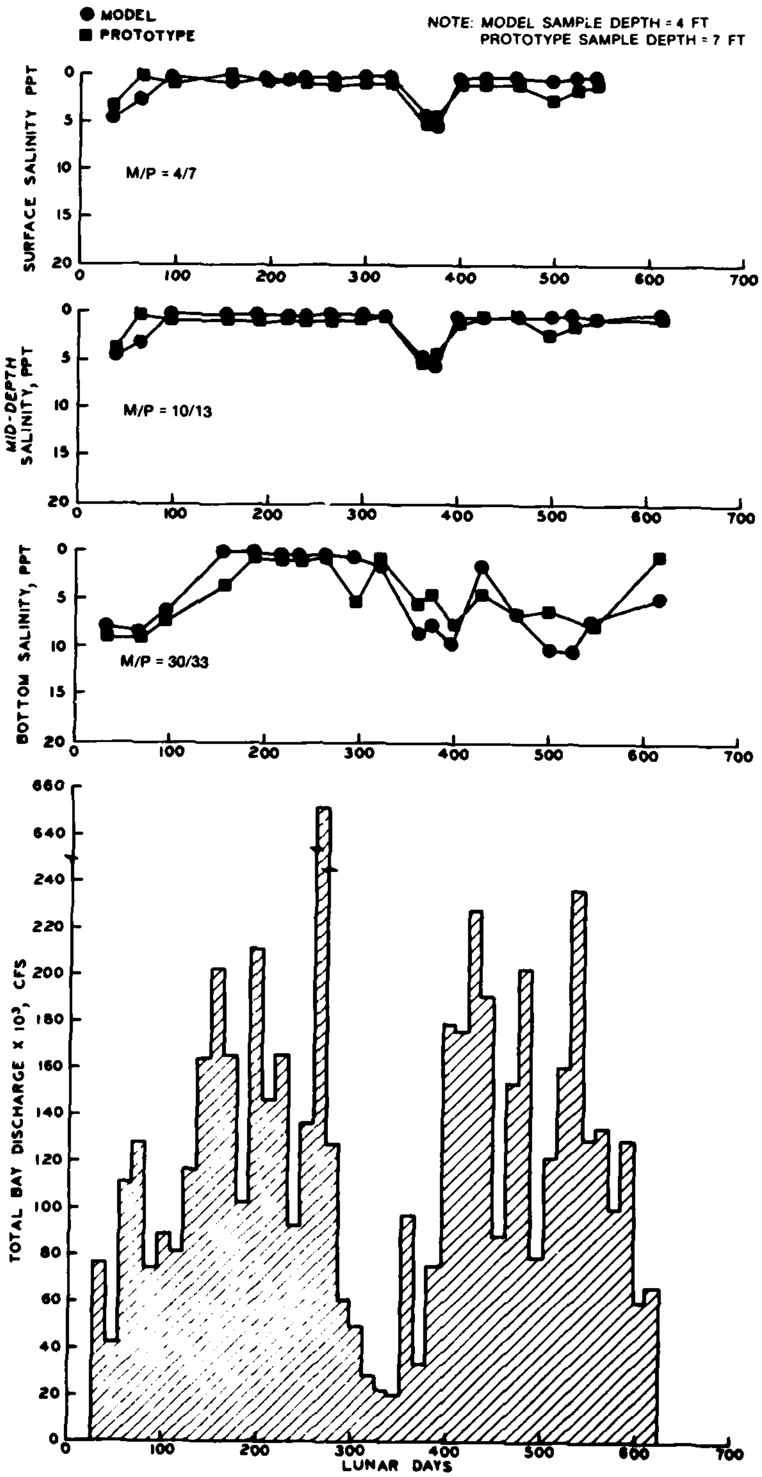
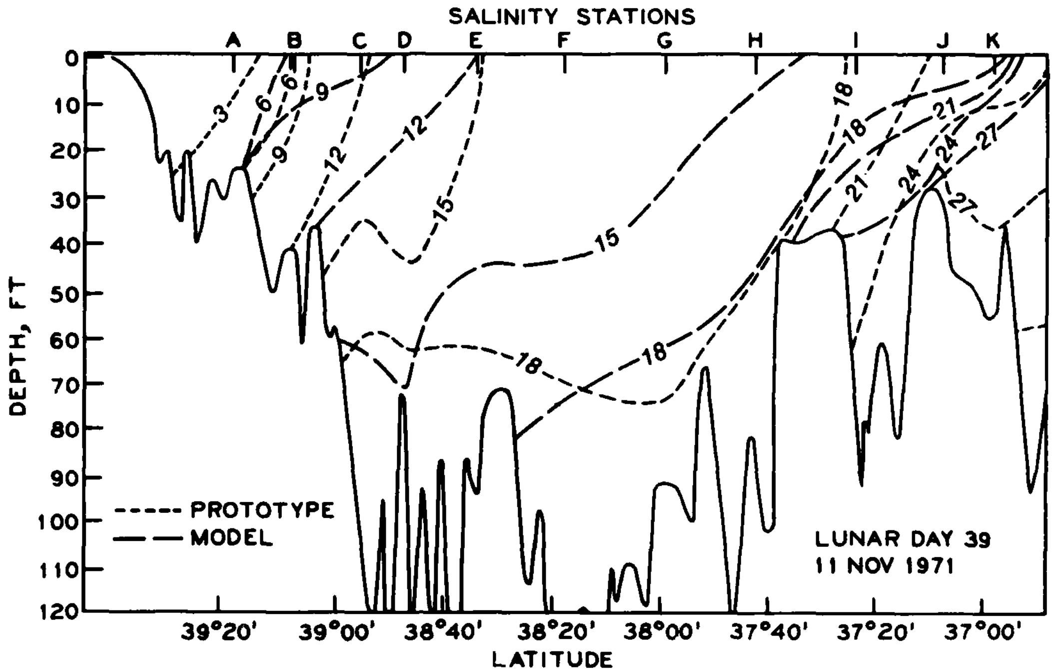



Plate D50. Model/prototype salinity comparison, sta K, Hydrograph III



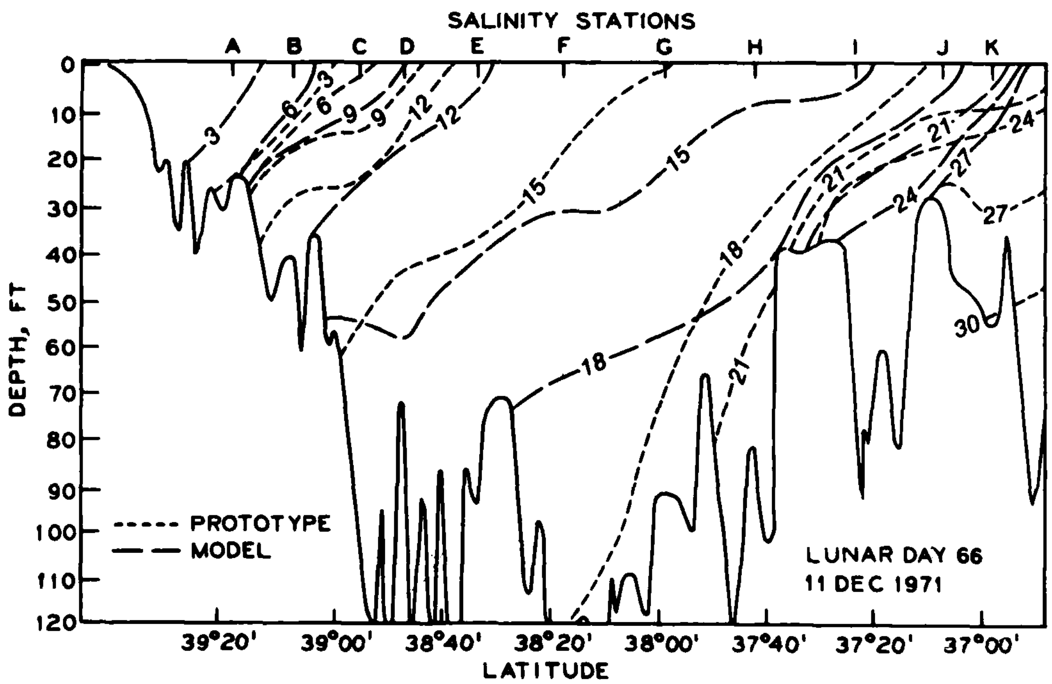
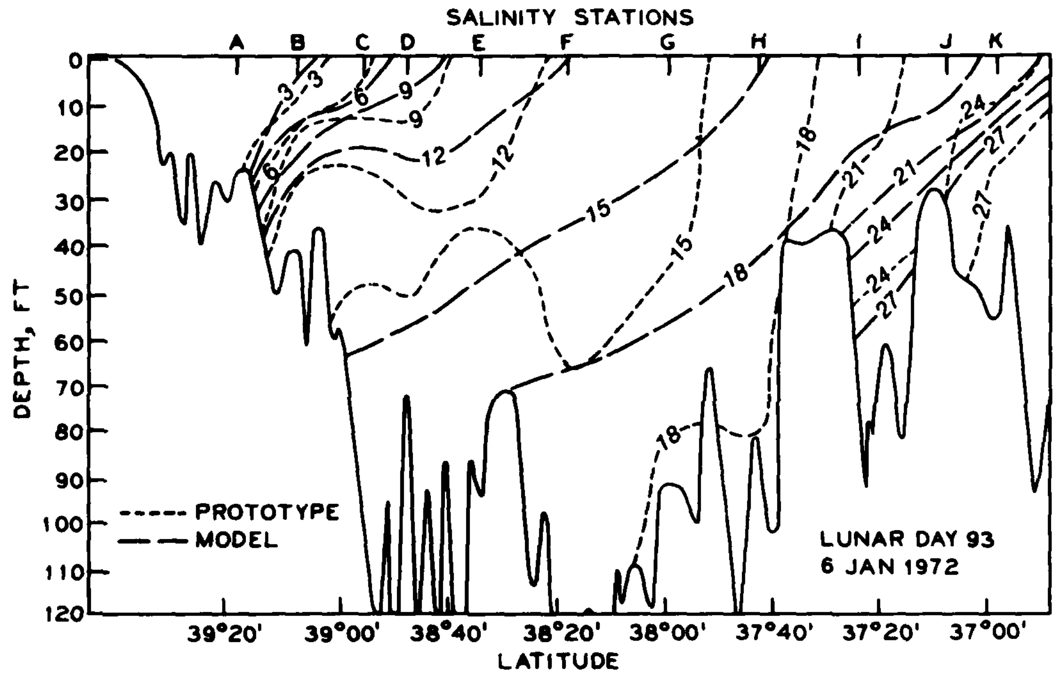




Plate D51. Model/prototype isohaline comparison, lunar days 39 and 66



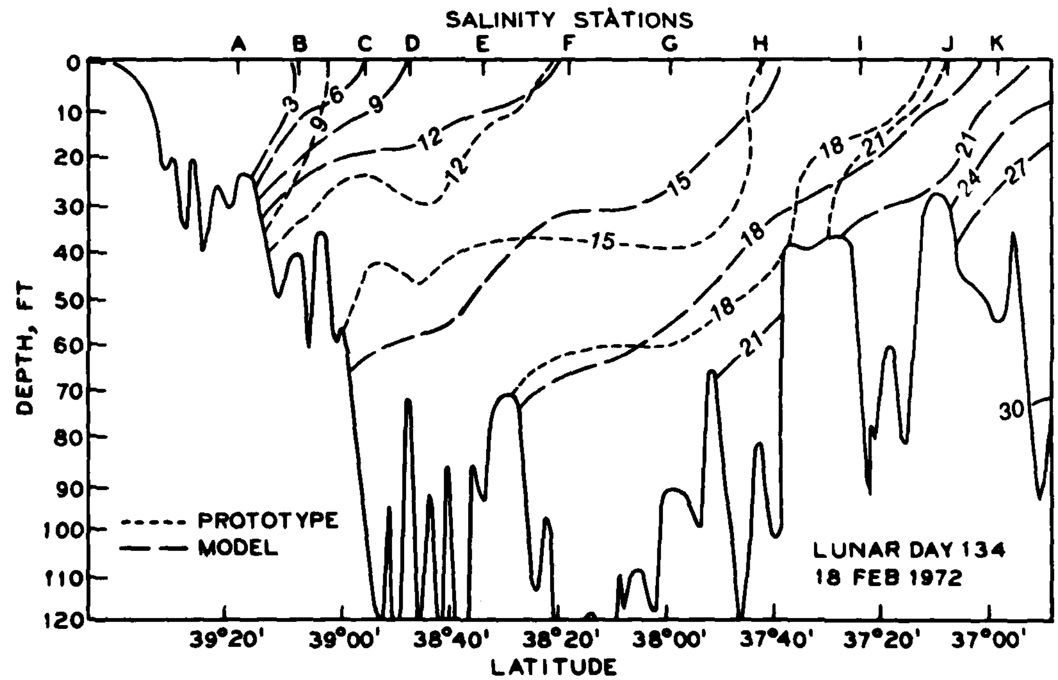
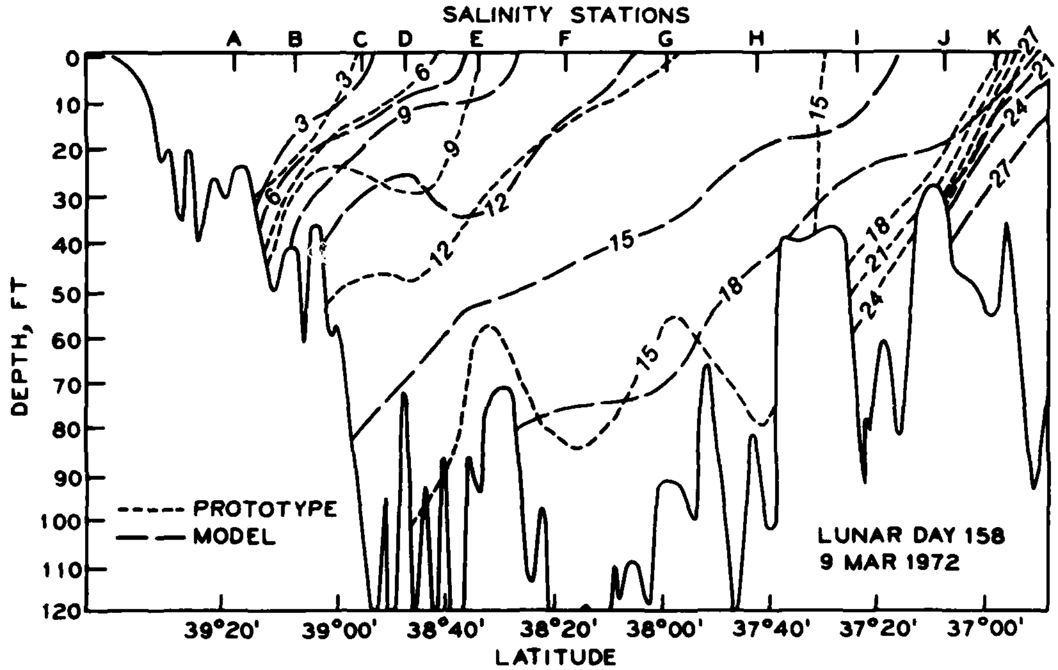




Plate D52. Model/prototype isohaline comparison, lunar days 93 and 134



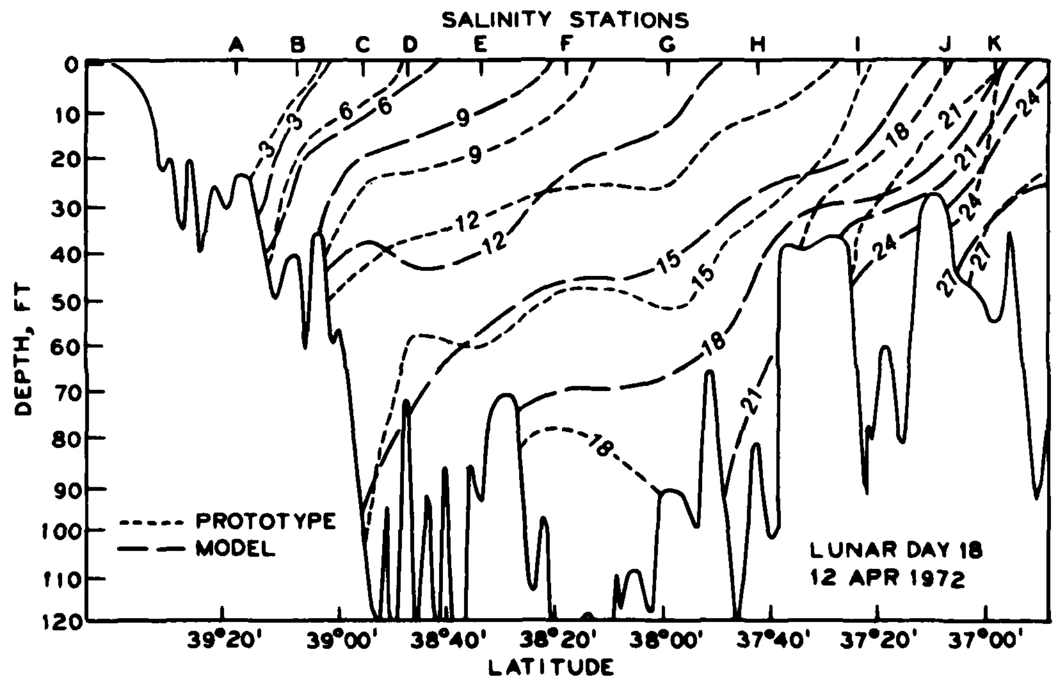




Plate D53. Model/prototype isohaline comparison, lunar days 158 and 18

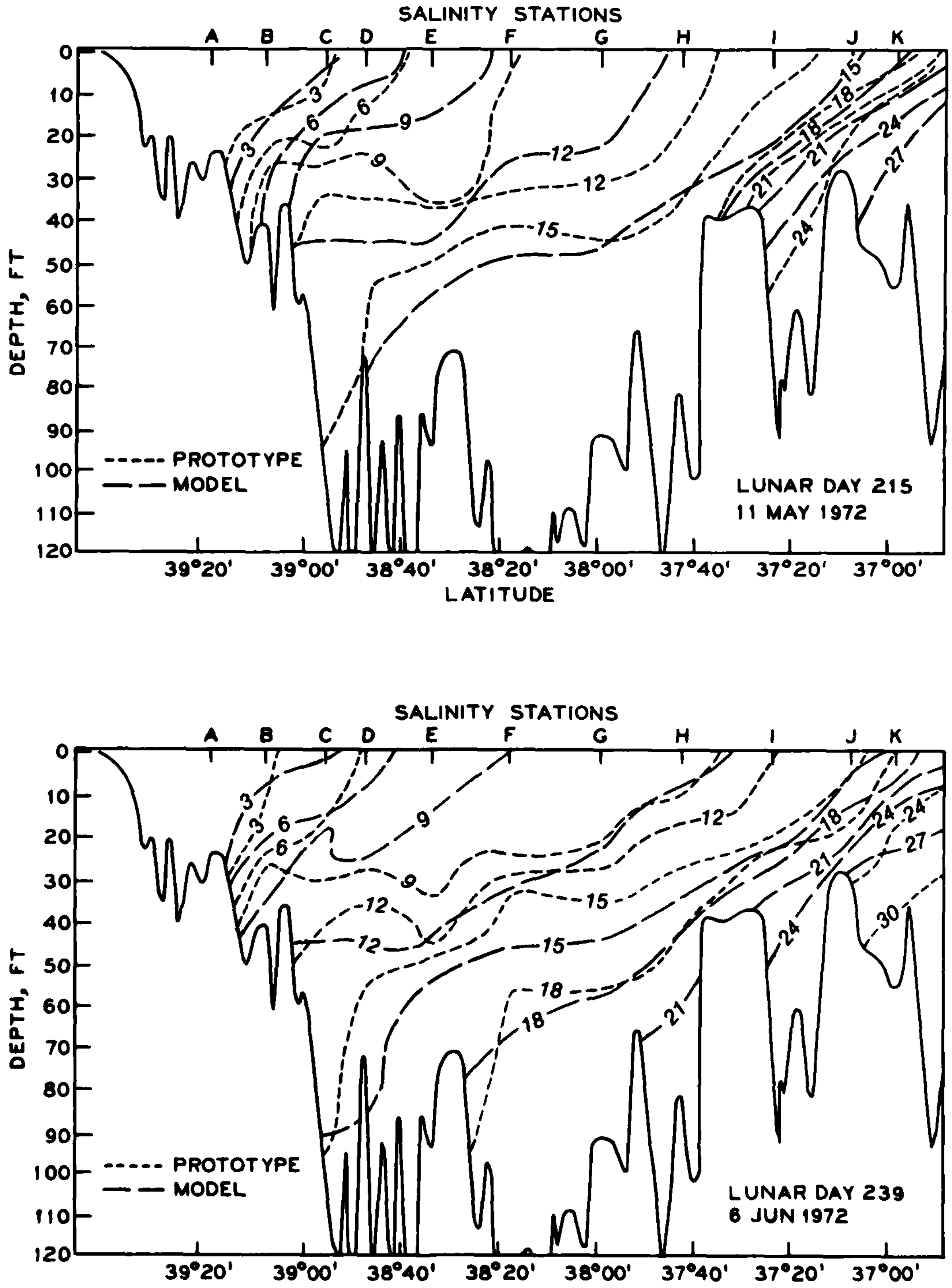
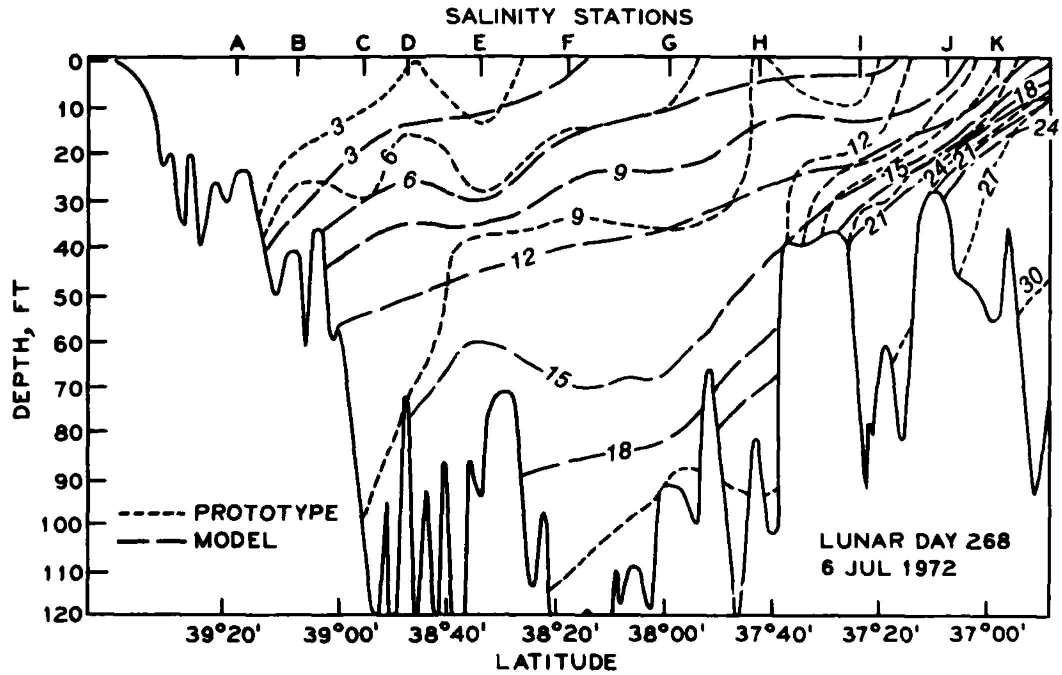



Plate D54. Model/prototype isohaline comparison, lunar days 215 and 239



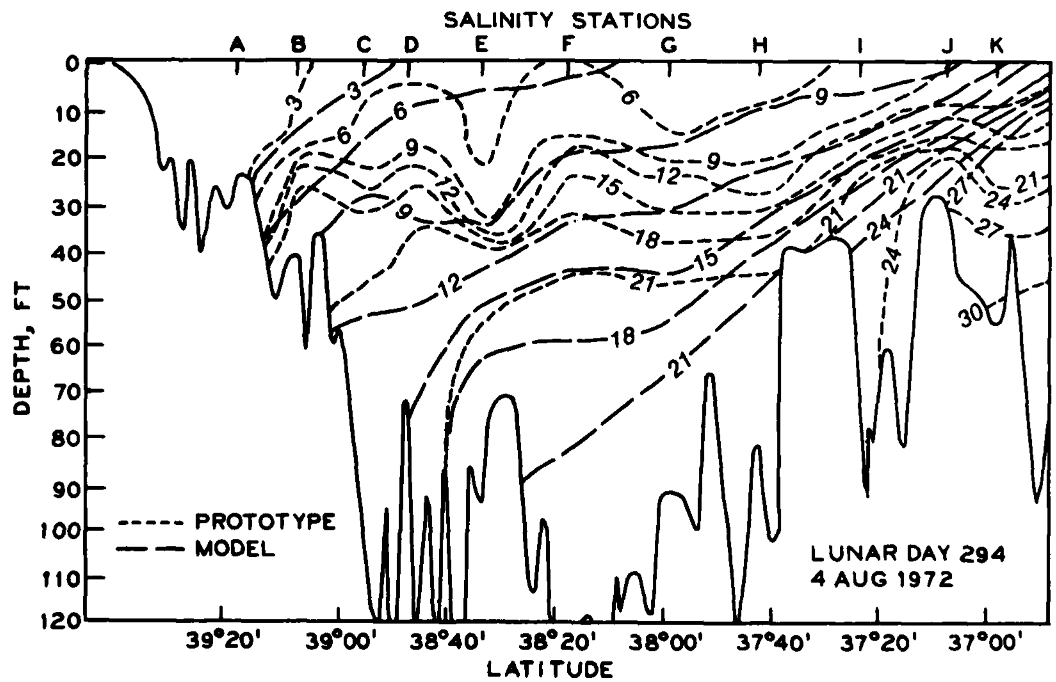
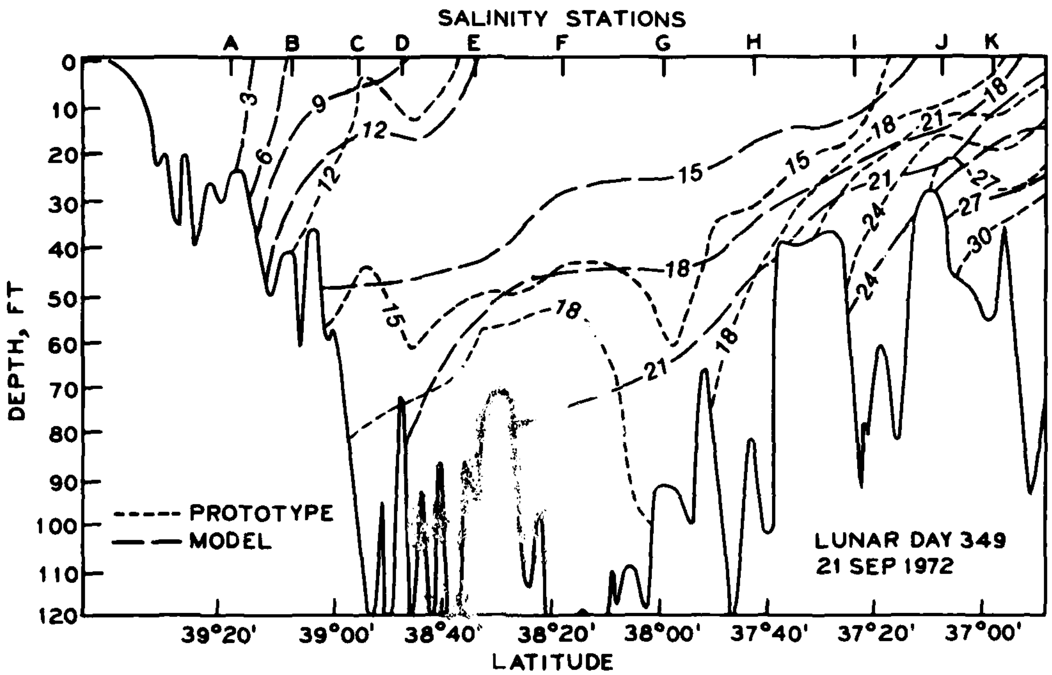




Plate D55. Model/prototype isohaline comparison, lunar days 268 and 294



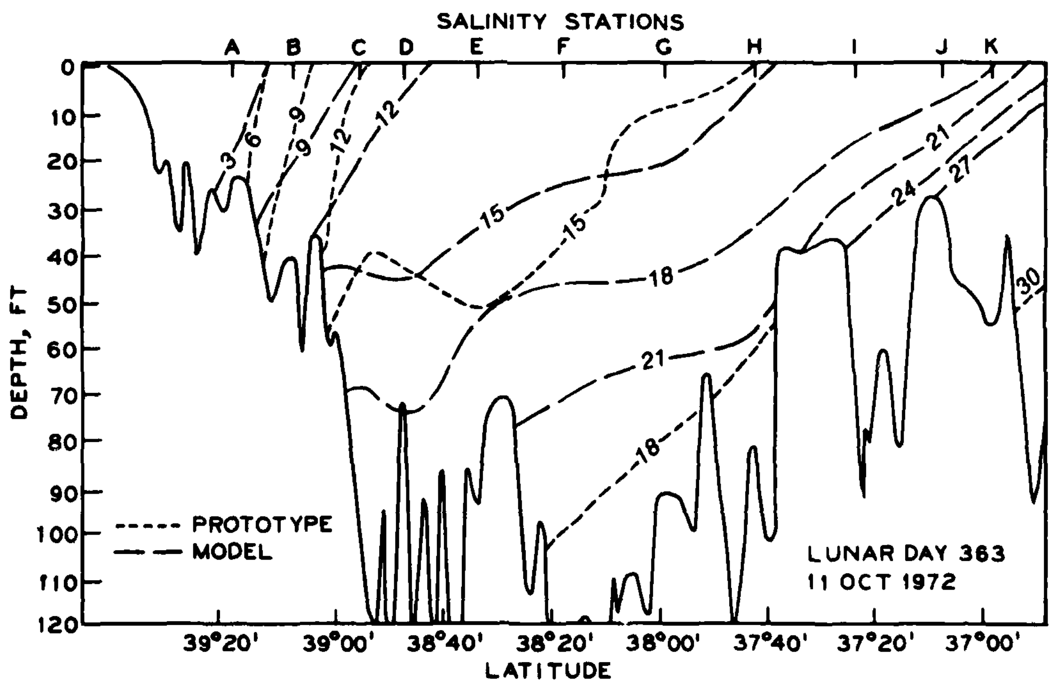
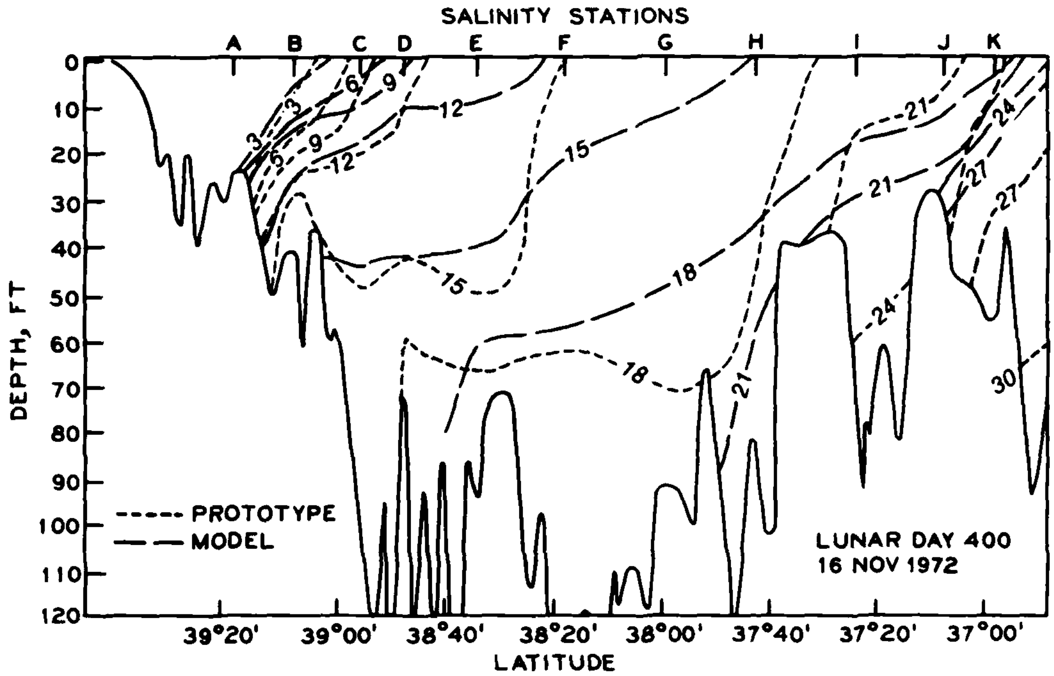




Plate D56. Model/prototype isohaline comparison, lunar days 349 and 363



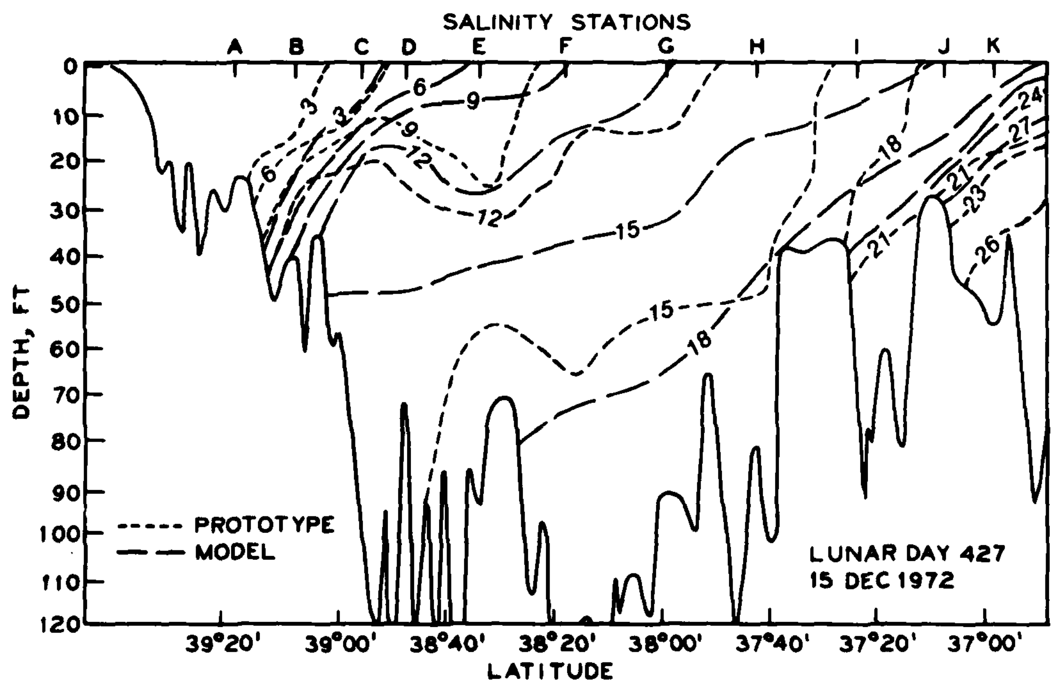
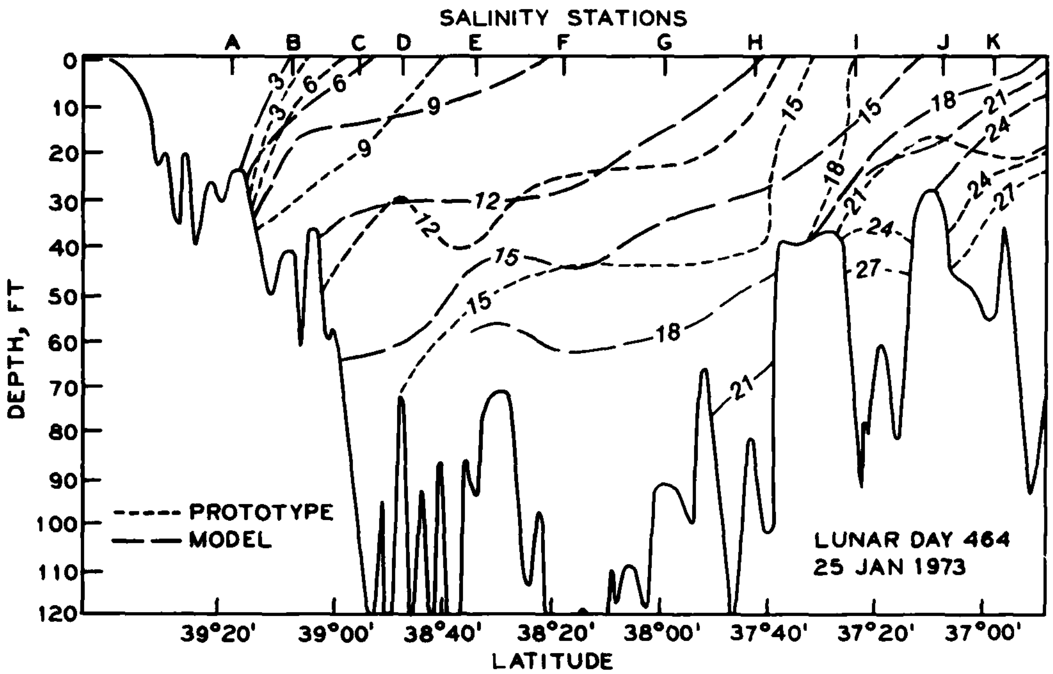




Plate D57. Model/prototype isohaline comparison, lunar days 400 and 427



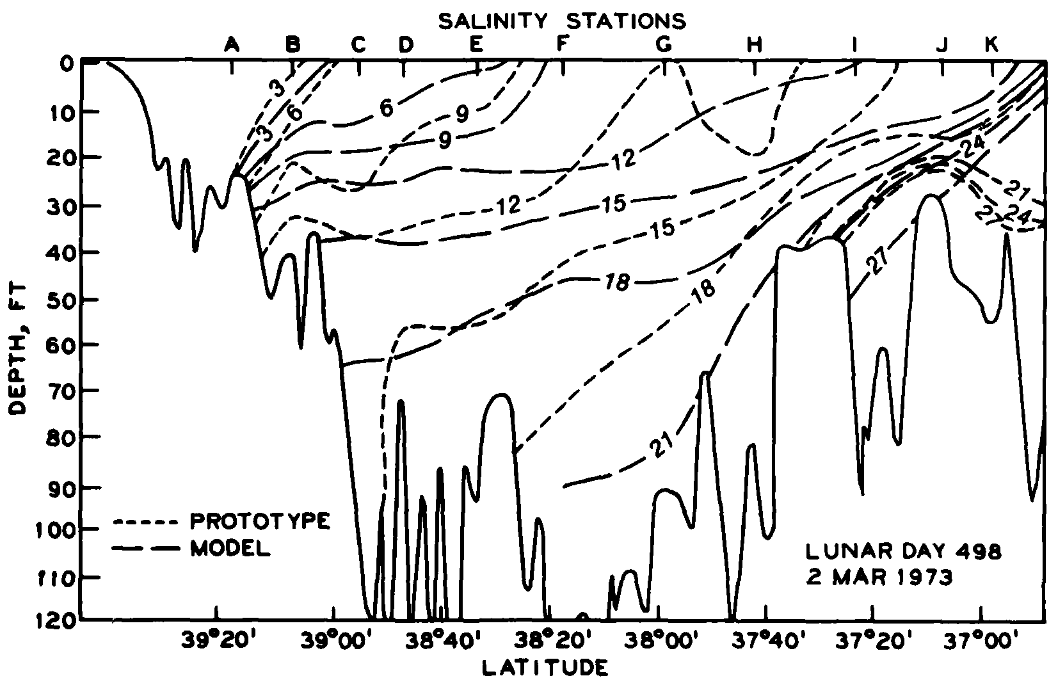
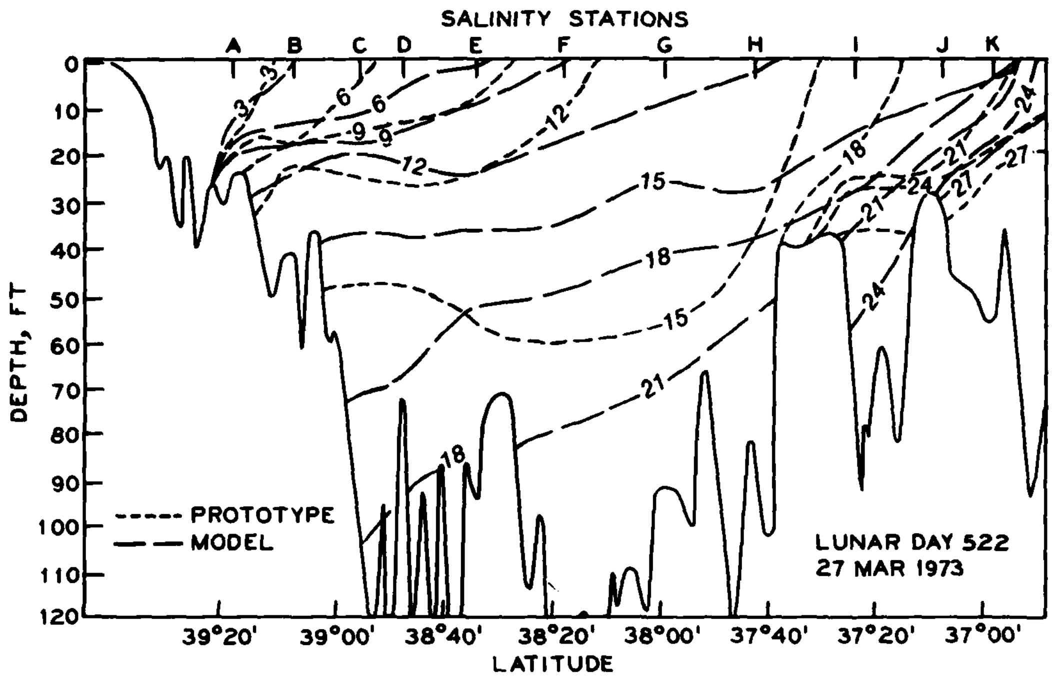




Plate D58. Model/prototype isohaline comparison, lunar days 464 and 498



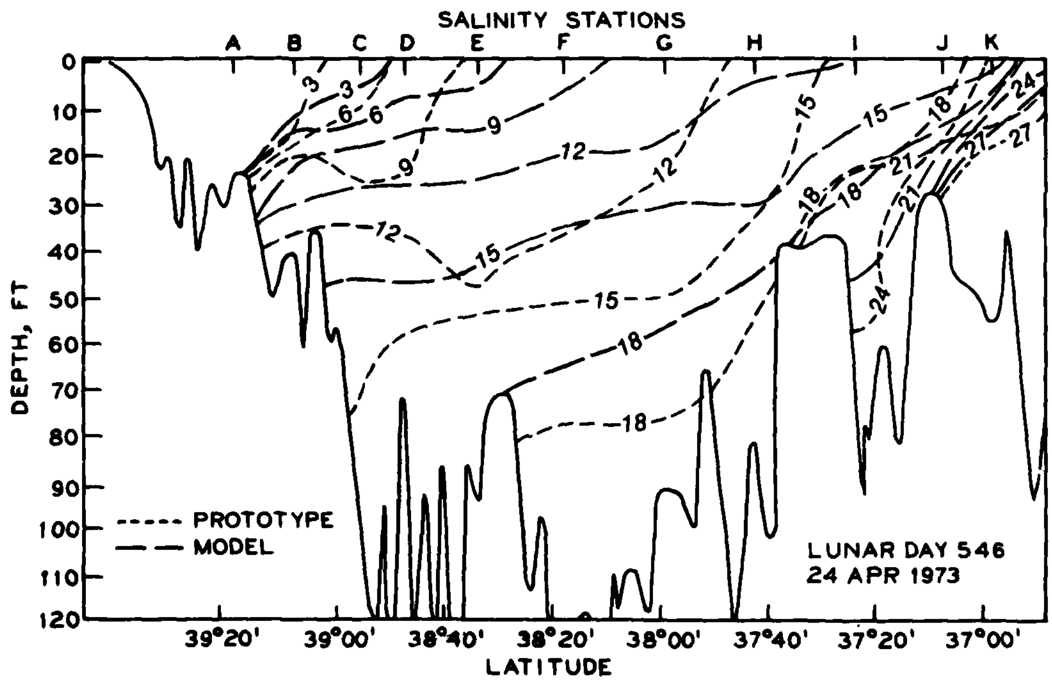
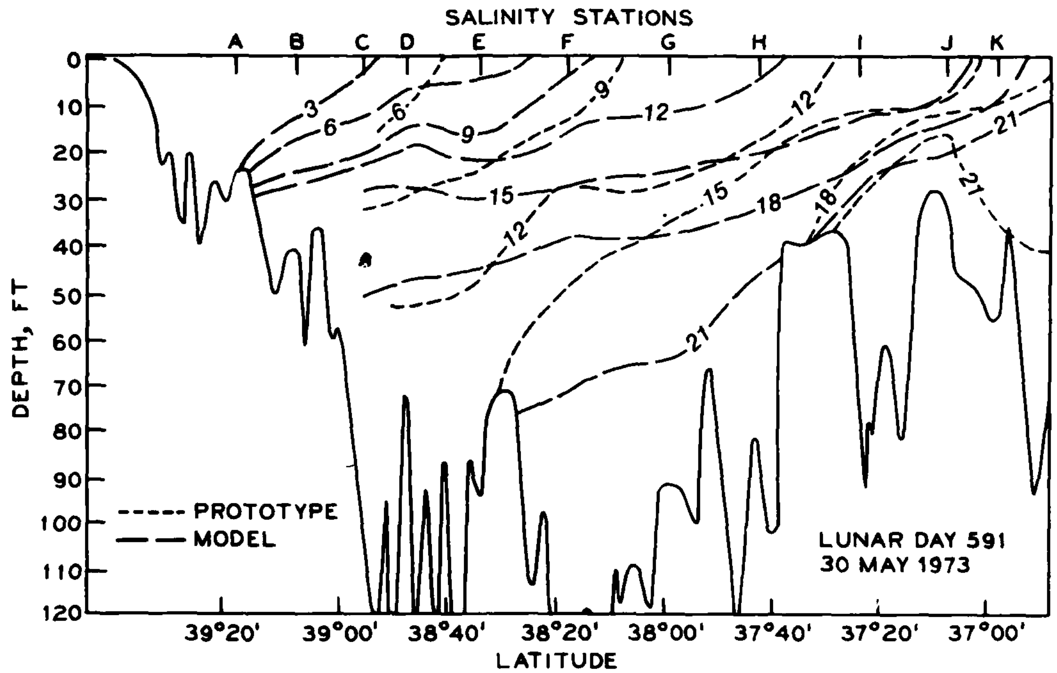




Plate D59. Model/prototype isohaline comparison, lunary days 522 and 546



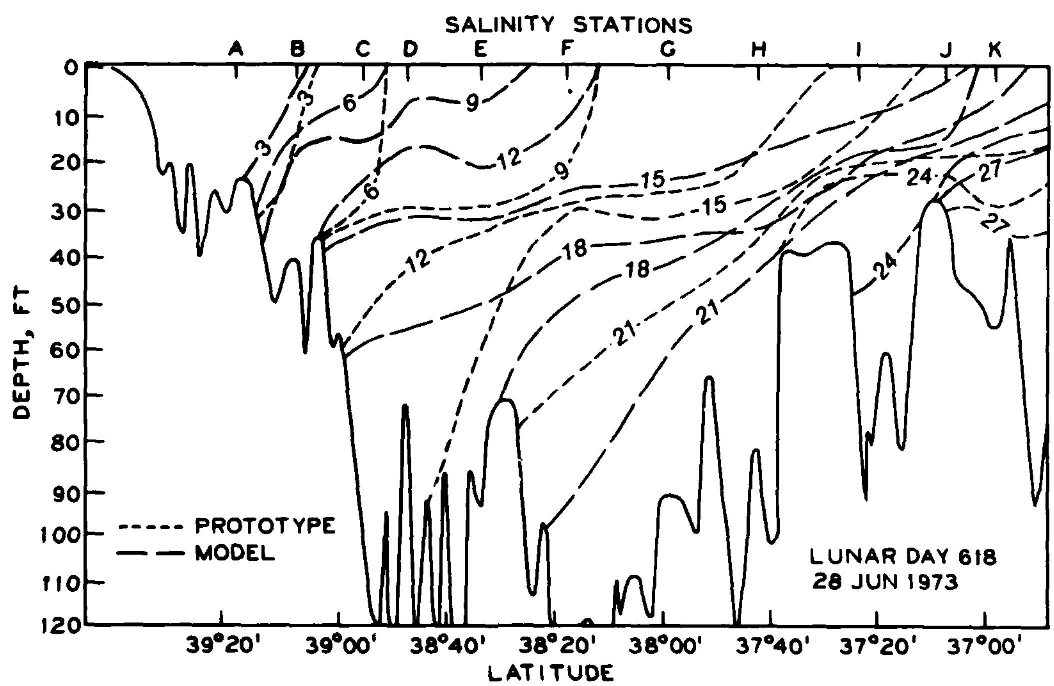
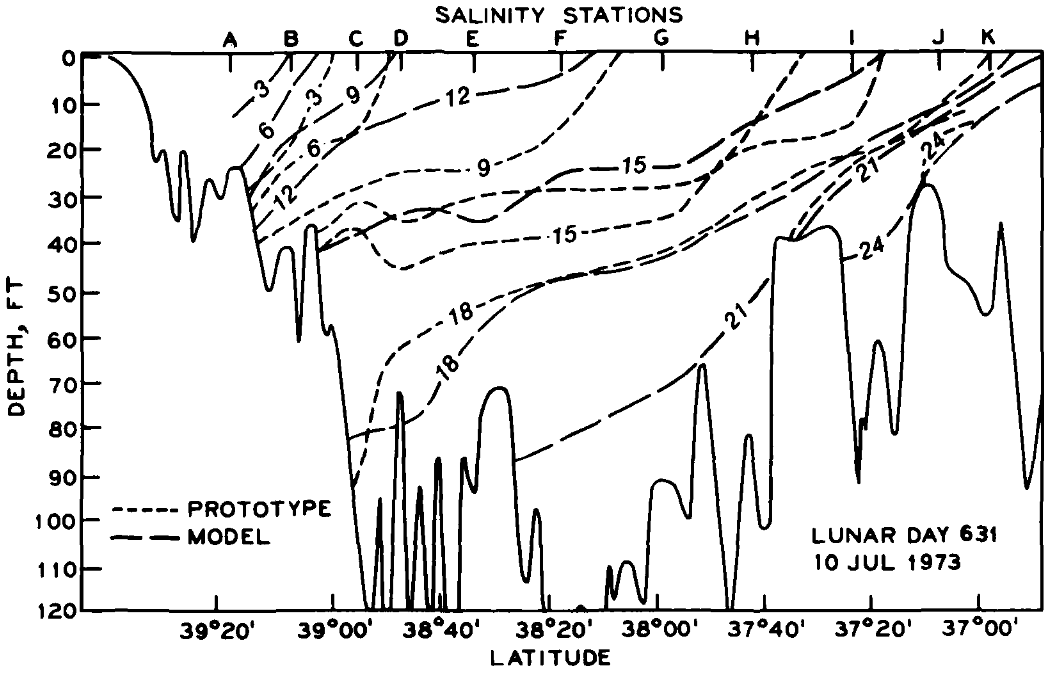




Plate D60. Model/prototype isohaline comparison, lunar days 591 and 618



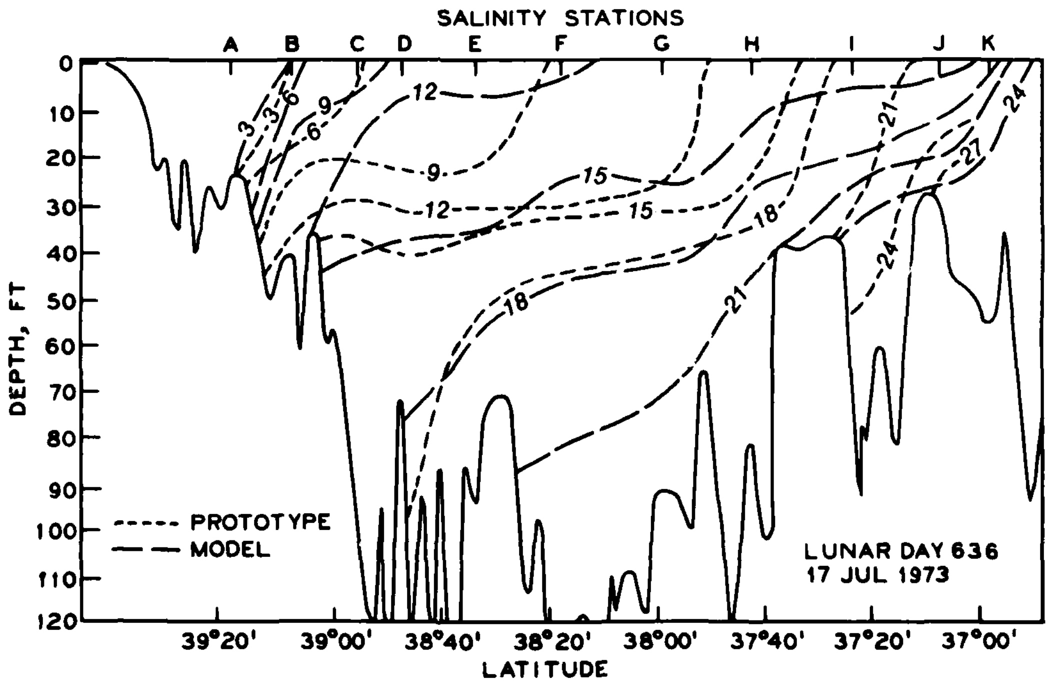




Plate D61. Model/prototype isohaline comparison, lunar days 631 and 636

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.


Verification of the Chesapeake Bay Model : Chesapeake Bay Hydraulic Model Investigation / by Norman W. Sheffner ... [et al.] (Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1981.

127 p. in various pagings, [175] p. of plates : ill. ; 27 cm. -- (Technical report ; HL-81-14)

Cover title.

"December 1981."

Final report.

"Prepared for U.S. Army Engineer District, Baltimore."

Bibliography: p. 75.

1. Chesapeake Bay. 2. Electronic data processing. 3. Hydraulic models. I. Sheffner, Norman W. II. United States. Army. Corps of Engineers. Baltimore District. III. U.S. Army Engineer Waterways Experiment Station.

Verification of the Chesapeake Bay Model : ... 1981. (Card 2)

Hydraulics Laboratory. IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; HL-81-14.

TA7.W34 no.HL-81-14